Repairing Circuit Boards

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Many small board repairs can be done with a methodical approach using basic tools such as DMMs and oscilloscopes to measure voltages and waveforms at significant test points in a circuit. Troubleshooting modern, complex, multi-layer PCBs is often challenging, with factors such as available documentation playing a role in the speed of repairs.   Automated systems may prove cost-effective for larger repair loads.

Anyone interested in electronics is bound to encounter a dead board or two, whether your own or someone needing help. What is the best approach when confronted with a PCB that doesn't do what it's supposed to do?

Circuit boards are more complicated to repair today than even a few years ago. Manufacturing mistakes and in-service component failures have become commonplace. Older circuit boards can malfunction due to components that fail – notably electrolytic capacitors – but new ones (assuming the layout is correct) might not work due to manufacturing errors, parts poorly or incorrectly soldered, solder bridges, etc. While simple soldering and component changes may be suitable for less complex fixes, some repairs may require more expert approaches to find fault causes. Repairing complete PCB assemblies can seem intimidating, but a methodical approach helps in finding and fixing problems quickly.

FIG.1 PIERCING PROBES
PENETRATE CONFORMAL COATING

It is wise get a report from the end-user about how the board failed. Did it ever work correctly? Did you just run a software update and killed it? Can you see any obvious fault clues such as broken wires or tracks? Usually it is wise to refrain from to powering up a damaged PCB at first. If, for instance, a simple blown fuse is suspected, the reason for the issue must be determined rather than just replacing the fuse (with a bigger one!) Short circuits or overloads usually leave tell-tale signs.

If the PCB has been conformally coated to keep out moisture and dust, this layer must be removed (at least at a few critical test points) before for fault diagnosis can begin. Conformal coatings may need to be removed by solvents, peeling, or blasting, but a new technique is being developed whereby the coating can be pierced through with very sharp test pins (see Fig. 1).
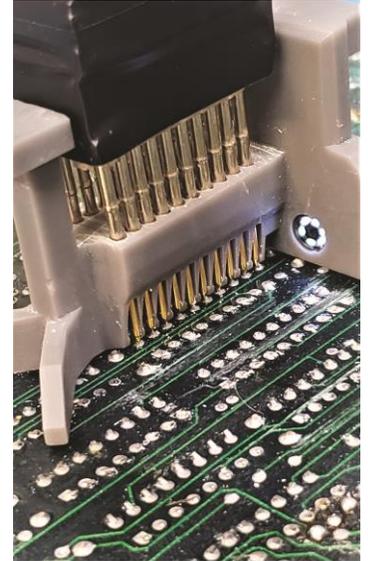

FIG.2 TYPICAL BENCHTOP INSTRUMENTS
LCR METER OSCILLOSCOPE DMM SPECTRUM ANALYZER

Before commencing the repair, gather together any relevant circuit diagrams, known good boards, and the appropriate test equipment, such as a DMM, solder/desolder hand tools, an oscilloscope, power supplies, etc. (Fig.2) preferably on a static-free bench. The most helpful "tool" to start with is the user report of how the failure occurred or what fault was observed. The most versatile tool is the multimeter, but depending on the complexity of the PCB, an LCR meter, oscilloscope, power supply, and logic analyzer may also be needed to investigate the operation of the circuit. RF circuits may need more sophisticated tools such as a spectrum analyzer to check frequencies and signal levels.

FIG.3 SOLDER BRIDGE SHORT CIRCUIT
REVEALED ON MICROSCOPE

Here are some strategies to streamline the process of reworking and repairing PCB's. Troubleshooting is also much easier if a known good board is available so that visual and signal comparisons can be made. Lack of a comparative board or documentation makes the challenge more daunting.
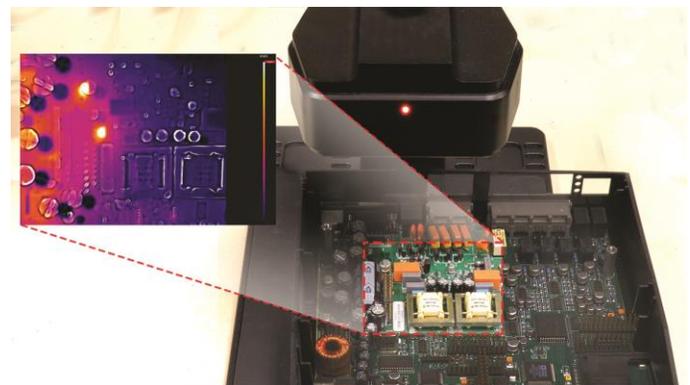
Visual

Check for loose connectors or components in sockets, which can often get dislodged in shipping. Look for burned or damaged parts, or solder bridges causing a short-circuit of signal or power lines. This is where a high power digital microscope is really useful! (See Fig. 3) Visual inspection is an essential first step in troubleshooting.

Visually inspect capacitors. If leaks, cracks, bulges or other signs of deterioration are evident, replace the capacitor with an equivalent type and voltage rating. Capacitors have a limited life and are often the cause of a malfunction.

Look for broken leads on the components. Some devices have tiny leads that can easily break off at the circuit board. IC legs can become bent during assembly. Look for cracks on the circuit board, leading to broken circuit traces or broken components.

Components or parts such as transformers, power output transistors, resistors, and capacitors that show a burn mark can be detected easily by observation. Apparent burns and brown stains (and an awful smell) can identify the overheated components but you need to find out why they overheated. A poor solder joint or bridge is another common item found during a visual inspection. Good solder joints always look smooth, bright, and evenly flowed. A dull surface can suggest a defective joint. Are there any solder bridges between tracks? Reversed or incorrect components?

Short circuits can be very tricky to troubleshoot. A momentary power-up test may indicate that a short exists, but often the location of the short is elusive. You can spend a long, frustrating time trying to locate a single short, particularly an interlayer short. Briefly powering up the board after spraying with freezer spray is the poor man's way to find shorts, which will heat up an area on low resistance in power lines. A more sophisticated method is to observe with a thermal (IR) camera to show a location that heats up more than the surrounding components. (See Fig. 4) Power the rail voltage with something less than the 3.3V or 5.0V required, and limit the power supply current too. Start with low volts/amps and bring both up slowly. PCBs may have a

**FIG.4 HOT SPOTS AND SHORT CIRCUITS
SHOWN BY THERMAL CAMERA**

self-limited life through the poor design of excessive component heating, inadequate heat sinks, or heat sinks with dried out heat-sink compound.

A quick way to find a fault is to compare the thermal images of a known "good board" with the device under test. Significant temperature differences can highlight the fault location. Using this approach, entire complex boards can be inspected in a non-contact manner. Common defects such as power-to-ground shorts and bad components, can quickly be found with this method. A changing or different color representation of the image may indicate overheating in a solder joint, circuit trace, or show a portion of the board that is malfunctioning.

Laboriously testing every resistor, capacitor, diode, transistor, inductor, MOSFET, LED, and discrete active component can be done with a multimeter or LCR meter but is not an efficient way to do debugging.

Simple Tests

If the board can be powered up, a digital multimeter can be used to check rail voltages at ICs, outputs of voltage regulators, and obvious signals such as clocks, correct/expected logic and I/O levels. An oscilloscope can be used

to verify voltage waveforms and communications of a powered board. To check for the presence of a PCB's WiFi signal output, even a cellphone can come in handy.

Leaky capacitors can be found using the resistance setting of the DMM. Set the meter to read in the high ohms range, and touch the meter leads to the corresponding leads on the capacitor, red to positive and black to negative. The meter should start at zero and then moving slowly toward infinity. With large capacitance values the ramp will be very slow. Note: a good capacitor stores an electrical charge and may remain energized after power is removed. Before taking a measurement of electrolytics, disconnect the power, and carefully discharge the capacitor by connecting a resistor across the leads. With the meter in the ohms setting, there will be some constant current sent out from positive to negative leads. An open cap will show open, a shorted one will show close to zero ohms.

Checking the operation of HMI interface items such as touch panels and switches may reveal functional issues due to connection or component problems.

Signal probing with a DMM or oscilloscope requires some understanding of the circuit to interpret the result, but is made so much easier if you have a known "good board" to compare point-to-point results. DC voltage tests start by probing with reference to ground. When checking an IC, start by testing the voltage supply pin. Most ICs can be identified by their markings and many can be operationally tested against their published specifications using scopes and logic analyzers. Comparing the behavior of an IC to a known one is a quick way to identify anomalous behavior. An engineer's favorite habit of touching low-voltage parts of a circuit can change impedances, which, in turn, can alter the behavior of the system (or else inadvertently find overheating!) Used in conjunction with a scope, this technique can help identify locations that need additional capacitance to remove unwanted oscillations, for instance.

Intermittent failures are the most challenging and time-consuming aspect of the troubleshooting process. Common irregular faults can be due to component overheating or degradation, poor soldering, and loose connections. Long memory in a scope can be helpful for zooming in to a signal record for finding rare events. Applying freezer spray in the right location can sometimes aggravate and identify intermittent issues.

How Do the Big Boys Do It?

Professional repair houses and repair centers that fix boards all the time need better solutions than a scope and a DMM. In situations where faulty PCBs come in a steady stream, and with the increased emphasis on efficiency and reduced costs, universal automated test systems have replaced individual test instruments. PC-based In-Circuit Testers perform both a powered, in-circuit logical test of digital and many analog ICs, as well as V-I signature analysis of the chips, using a variety of test clips. Automated Testing Equipment (ATE) systems that contain libraries of digital chip pinouts can assist the technician in troubleshooting, and also determine wiring patterns of the circuits if not known. ATEs can check for digital functionality

FIG.5 ABI SYSTEM 8
AUTOMATED TEST EQUIPMENT

of ICs, and also provide a signature analysis of both active and passive components. Unknown chips can be identified by their Boolean output.
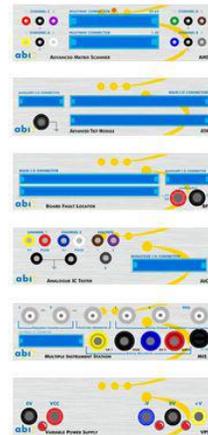
Acquiring automatic testing equipment means that frequent repairs can be performed in-house more efficiently than sending the items to an outside service. Some ATEs can be extremely expensive and may come with a steep learning curve, meaning that after purchase they sit idled in a store room. ATEs can perform automated or computerized test procedures on a device under test, including functional testing of ICs, analog and digital components, complete boards, etc. These products vary in complexity depending on the different levels of test capabilities needed for various board needs. Computer-based automated test procedures can run reliably and consistently with test results being captured automatically, with high accuracy, at high test speeds, and with extreme flexibility. Typical ATEs include: In-Circuit Testers, performing device level tests on components

mounted circuit boards; Functional Testers, used to test full functionality of boards and modules via edge connectors; Boundary Scan Testers for products that are JTAG-compliant such as BGA, FPGA, CPLDs, or even complete boards with a JTAG connector.

An example of an ATE PCB repair system is the ABI Electronics System 8 - a board test system that uses a selection of CD-drive-size modules to create a customized PC-driven PCB test station. Built in a PC case or 19" rack-mount, System 8 is a mix-and-match set of test instruments to suit most testing and fault-finding needs. Comparing results from a known good board with automated-sequence fault-finding procedures, fault diagnosis becomes possible by minimally-trained staff. The System 8 software can be configured to guide less well-trained users step-by-step through a test procedure, with custom-annotated picture images, instructions, and attached datasheets to give quick Pass/Fail results. This is much faster and more economical than using traditional oscilloscopes, meters and other bench test methods. System 8 modules (Fig. 5) include:

- **Board Fault Locator**: 64 test channels for multiple test methods for fault diagnosis and functional testing of digital ICs (in-circuit / out-of-circuit), IC connections status, and voltage acquisition, V-I Curve testing of components on unpowered boards.
- **Analog IC Tester:** for in-circuit functional testing of analog ICs and discrete components (no programming or circuit diagrams needed). Fully configurable V-I Tester for detection of faults on unpowered boards.
- **Multiple Instrument Station:** includes 8 high specification test and measurement instruments in one module (Frequency Counter, Digital Storage Oscilloscope, Function Generator, Digital Floating Multimeter, Auxiliary PSU, and Universal I/O).
- **Advanced Test Module**: offers powerful test combinations for flexible, comprehensive fault diagnosis, including functional, connections, voltage, thermal and V-I signature tests.
- **Advanced Matrix Scanner:** 64 channels for fast data acquisition to test high pin count devices as well as complete PCBs; sweep signal frequency to observe device under test response over a frequency range.
- **Triple Output Variable Power Supply:** provides required supply voltages to the unit under test.

ATE applications include: PCB testing and troubleshooting, digital/analog IC test, digital/analog V-I test, visual short identification with audible/visual indication of probe distance to short, live board comparison, manufacturing defects analysis, power-on/power-off testing, QA reporting, embedded real-time control, calculation and logging, component and board testing, digital and analog functional tests, automated test sequences, etc.

Power Off V/I testing

If a board can't be powered up safely, then power-off testing such as V/I and Signature Testing can be performed. V/I testing (also known as Analog Signature Analysis) is a technique which is excellent for fault finding on PCBs, and is ideal when diagrams and documentation are minimal. Analog Signature Analysis can be done with instruments such as ABI Electronics' System 8 ATM Advanced Test Module (Fig.5). This method can be used to perform powered-off troubleshooting of electronic components in printed circuit board assemblies. It could be considered a vital diagnostic tool for PCB repair tasks since it is suitable for 'dead' boards which cannot safely be powered up.

Applying a current-limited AC signal across two points on a circuit causes vertical deflection of the scope trace, while the applied voltage produces a horizontal deflection. This forms a characteristic V/I signature that can show if a component is good, bad or marginal. In order to employ the V-I tester to its full potential as a fault diagnosis tool, it is important to focus on differences between curves for good and suspect boards, rather than analysing in

great detail the meaning of the curves. The majority of nodes on a PCB will contain parallel and series combinations of components, making exact analysis difficult. The majority of faults on failed boards are major failures such as short or open circuits, which are easy to detect with the V-I technique without complex analysis.
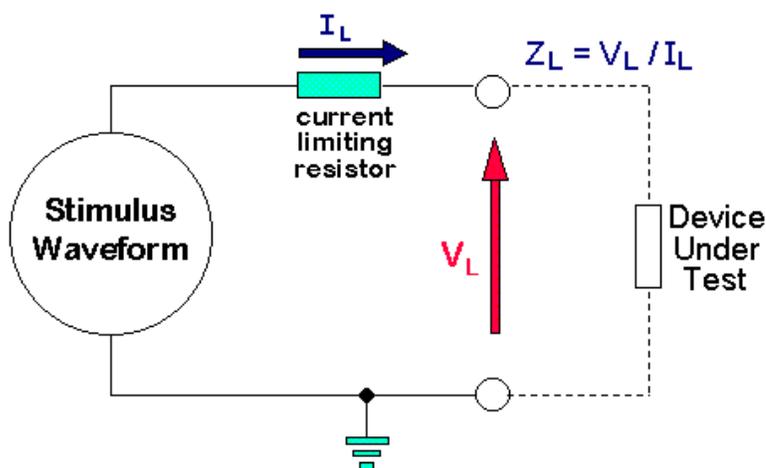

The voltage across the DUT is plotted on the horizontal axis against the current through it on the vertical axis. The stimulus waveform is usually a sine wave. From Ohms law, $(Z = V/I)$ the resulting characteristic represents the impedance of the DUT. For frequency dependent components such as capacitors and inductors, the impedance is frequency related, so a variable frequency stimulus is required.

Most applications use comparative analog V-I testing, so understanding the displayed characteristic is not necessary. The comparison of the curves for a known good board and a suspect board can often identify faults with a minimum of knowledge. Different devices in different configurations produce different signatures, depending on the current flow through the device as the applied voltage changes. A short circuit, for example, would be displayed as a vertical line, because the current flow for any applied voltage would be theoretically infinite (see below), whereas an open circuit would display a horizontal line because the current is always zero irrespective of the applied voltage (see below). A pure resistor would give a diagonal line whose slope is proportional to the resistance, because the current is proportional to the applied voltage. More complex curves are obtained with frequency dependent components such as capacitors and inductors, and also for non-linear devices such as diode and transistor junctions.
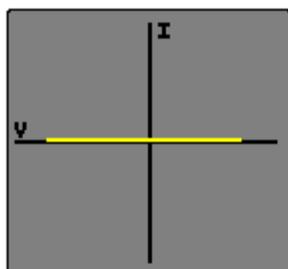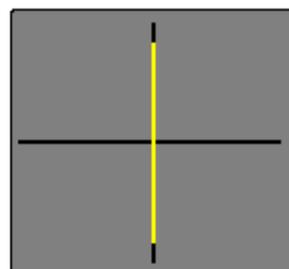

The signatures of resistors are straight lines. The value of the resistor under test affects the slope of the line, the higher the value, the closer the line gets to the horizontal (open circuit). The source impedance of the V-I tester should be selected so the slope of the line, for a good resistor, is as close as possible to 45 degrees. A difference in the slope of the curve when comparing a good and suspect board would indicate a difference in the resistor values on the two boards. Capacitors with relatively low values have flattened, horizontal, elliptical signatures and capacitors with relatively high values have flattened, vertical, elliptical signatures. The optimal signature is a nearly perfect circle (see Diagram 2) which can be obtained by selecting the appropriate test frequency and source impedance. Typically, the higher the capacitance, the lower the test impedance and frequency. A leaky capacitor would give a sloping curve due to the effective resistance in parallel with the capacitor.
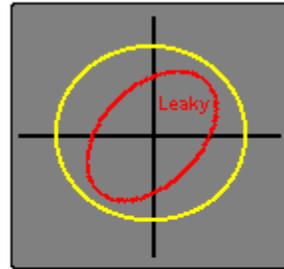
Diagram 1:
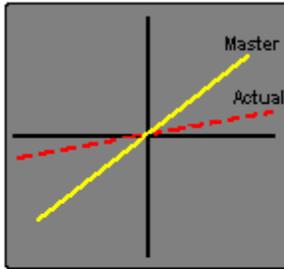
820 Ohm Resistor
SETTINGS
Frequency :   1.2kHz
Source Impedance : 1k Ohms
Curve :   sine wave
Voltage :   10V peak to peak

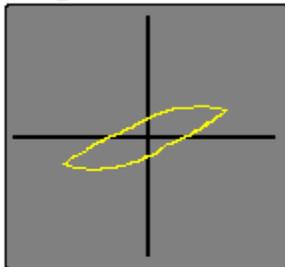## Diagram 2:

0.47uF Capacitor
SETTINGS
Frequency :   4.8kHz
Source Impedance : 100 Ohms
Curve :   sine wave
Voltage :   2V peak to peak

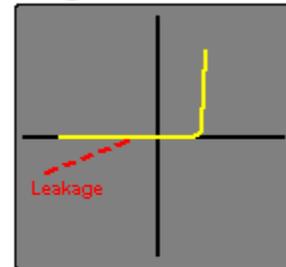## Diagram 3:

10mH Inductor
SETTINGS
Frequency :   1.2kHz
Source Impedance : 100 Ohms
Curve :   triangle wave
Voltage :   4V peak to peak

Diagram 4:

1N4148 Diode
SETTINGS
Frequency :   60Hz
Source Impedance : 1k Ohms
Curve :   sine
Voltage :   6V peak to peak

Diagram 5:

BZX55C5V1 Zener Diode
SETTINGS
Frequency :   60Hz
Source Impedance :   1k Ohms
Curve :   sine
Voltage :   20V peak to peak

Diagram 6:
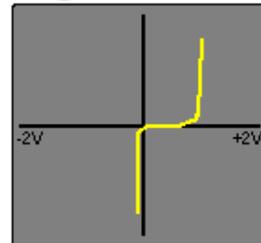
PNP Transistor
SETTINGS
Frequency :   120Hz
Source Impedance : 1k Ohms
Voltage :   4V peak to peak
Pulse Type :   Bipolar : (V+ 0.12) (V- -0.7V)
Positive start :   0us stop : 4.18ms
Negative start :   4.18ms stop : 8.33ms
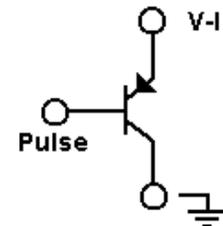
Summary

The choice of the troubleshooting method depends on the complexity of the circuit and the knowledge and experience of the person who performs the troubleshooting. The methodical use of relevant test tools helps investigators to identify the cause of failure quickly and accurately and thereby speed up PCB repair. Businesses realizing this economies of repair versus replace have started incorporating ATEs into their support infrastructure, to their financial and operational advantage.

PCB Repair Flowchart

Visual inspection
(Check for damaged components, broken tracks and signs of damage)

Can the PCB be powered up?

No → **Use V-I tests and traditional instruments**

- Check power rails for shorts
- Check fuses for open circuit
- Check caps/inductors for shorts
- Check resistors for open circuit
- Measure resistors values
- Check relays for shorts

Is a reference PCB available?

No → **Check for design similarities**

Check all discrete components with V-I testing

- Test transistors (V-I)
- Test transistors (V-T + pulse)
- Test diodes (V-I)
- Check thyristors, SCRs etc. (V-I)

Check all ICs with clips and V-I

- Use standard V-I
- Use 3D V-I
- Use matrix V-I

Replace components as required

Yes → **Power up PCB**

- Check current consumption
- Use current limiter
- Check PCB for heat

Check all voltages

- Measure all test points
- Measure regulators, converters
- Measure transformers
- Measure Vcc on familiar ICs
- Use DMM and DSO

Check clock signals

Check all human/machine interfaces

- Check switches, LEDs etc.
- Check displays

Run functional tests for digital devices

- Truth table
- Connections
- Voltage
- V-I
- Thermal

Run functional tests for analogue devices

- Functional
- Connections
- Voltage

Run custom tests

- Check relay activations
- Check ADC/DAC with MIS

Run JTAG tests