Library of Congress Control Number: 2020920430

ISBN 979-8-6863-4381-8

Cover design by Matchbook.

Printed in the United States.

First printing.

10 9 8 7 6 5 4 3 2 1

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CHAPTER 1

Before You Begin

Introduction

Baking a cake shouldn't require you to be a professional baker. And fixing your TV or laptop shouldn't require you to have a background in electronics. That's the idea behind this book. The information in this book can save you time and hundreds of dollars with a single repair.

The explosion of do-it-yourself (DIY) repair videos and other online resources has fueled a surge of interest in electronics repair for beginners. The growing right-to-repair movement means that consumers will demand more products that they can fix themselves. But repair videos and online repair advice are not always accurate, and there are many gaps in the information. This book complements what's online and fills those gaps.

This book will give beginners the confidence and know-how to repair electronics. It starts from scratch with the basics and advances to more complex repair techniques. It's filled with photos, diagrams, and charts to make the material easy to understand. But even experienced repairers will benefit from the know-how in this book.

How This Book Is Organized

If you have no electronics background, start with Chapter 2 and work your way forward. If you do have some electronics experience, you'll be able to move quickly through the material in the early chapters. But don't skip them entirely; there are useful tips for experienced repairers in every chapter.

- **Chapter 2, "Safety."** This chapter discusses safe working practices for electronics repair. Some hazards are obvious, but others, such as charged capacitors in electronics that are unplugged and off or high voltage in battery-operated devices, are not so obvious.
- **Chapter 3, "Electronics Basics."** If you're new to electronics, this chapter will introduce you to the basics of electronic components, block and schematic diagrams, and electricity.
- **Chapter 4, "Equipment and Supplies."** Repairing electronics requires some specialized supplies and equipment. You may already have some of what you'll need. The real value of this chapter is that it lets you discover something to make repairs faster, easier, cheaper, or better. It's organized by basic supplies, hand tools, and equipment from basic to advanced.
- **Chapter 5, "Soldering and Desoldering."** Knowing how to solder and desolder is a necessary skill for electronics repair. With some knowledge and a little practice, everyone can learn to solder well enough for basic repair work. This chapter provides the knowledge; you'll have to do the practicing on your own. This chapter also covers printed circuit board (PCB) trace repair, replacing heatsinked devices, and special techniques for surface-mount devices.
- **Chapter 6, "Using Test Equipment."** This chapter explains the basics of how to use the two most important pieces of test equipment for electronics repair: digital multimeters and oscilloscopes. This chapter shows what the equipment can be used for and its ease of use.
- **Chapter 7, "Part Identification, Testing, and Substitution."** This chapter is about how to identify parts, tell whether they're work-

ing, and find a substitute, if needed. The procedures for checking parts in this chapter assume that the part is out of circuit.

- **Chapter 8, "General Repairs and Troubleshooting."** This chapter provides repair guidance that can be applied to any electronic device. Topics include poor candidates for repair, taking it apart, what to look for in a visual inspection, likely suspects, intermittent problems, and in-circuit component testing. The second half of the chapter is devoted to the art of troubleshooting. Topics include resources for understanding the system, troubleshooting strategy, power supply troubleshooting, and transistor circuitry troubleshooting.
- **Chapter 9, "Product-Specific Repairs."** This chapter provides specific repair advice for the most commonly repaired products, including audio receivers, rechargeable battery packs, flat screen TVs, laptops, and remote controls.

CHAPTER 2

Safety

High Voltage

When repairing electronics, the most important safety concern is electrical shock. Any voltage higher than 50 volts has the potential to stop a human heart. If you're wet or the contact point penetrates the skin, even lower voltages can be lethal.

Any device that's powered by 120 volts AC and plugged in clearly has the potential to kill, but even devices that run on batteries or are unplugged can still electrocute you (see Table 2-1).

TABLE 2-1 Common Hazards in Electronics Repair

Hazard	Action
Device powered by 120-VAC line	Unplug from AC line while repairing
Stored charge in electrolytic capacitors	Discharge large capacitors
Inverter circuits	Remove power and batteries while repairing

Electrolytic Capacitors

Electrolytic capacitors can store high voltages for minutes or even hours. Large-capacity high-voltage electrolytics are common in the power supply circuits of many products and pose a potential hazard. You can use a DC voltmeter to check for electrolytics with a stored charge. It's a good idea to discharge any large capacitors measuring more than a few volts. The residual voltage can affect in-circuit measurements even if it's well below hazardous levels.

Some people use a screwdriver to electrically short the two terminals of a capacitor to discharge it, but this is a hazardous practice. It can produce a big spark and vaporize a chunk out of your screwdriver tip or capacitor terminal. In some circumstances, the capacitor can even explode. It's better to discharge a capacitor through a power resistor (Fig. 2-1). For more details, see the section "Capacitors" in Chapter 7.

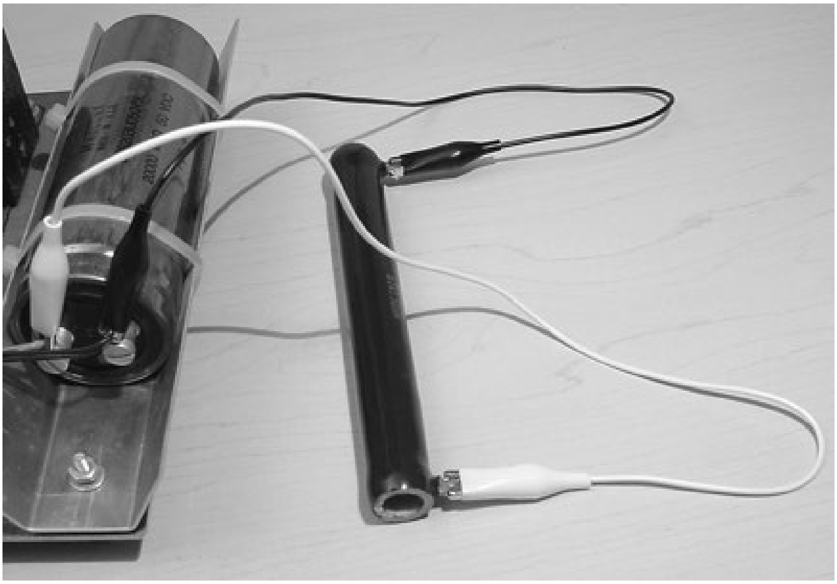

FIGURE 2-1 Discharging an electrolytic capacitor through a resistor.

Inverter Circuits

Inverter circuits convert lower voltages to higher voltages. For example, a voltage inverter is used to provide the several thousand volts needed

CHAPTER 3

Electronics Basics

If you're new to electronics, this chapter will introduce you to the basics of electronic components, block and schematic diagrams, and electricity.

Introduction to Components

Despite their wide variety of appearances, most electronic components are resistors, capacitors, diodes, transistors, or integrated circuits. Knowing what they look like and what they do is essential for repair work and is the purpose of this section. Specific part identification, part substitution, and typical failure modes are the subject of Chapter 7.

Resistors

Resistors (Fig. 3-1) implement electrical resistance as a circuit element. Resistors are used to reduce current flow, adjust signal levels, bias transistors, and many other things.

Potentiometers

Potentiometers (Fig. 3-2) are variable resistors with three terminals. The two outer terminals have a fixed resistance value between them. The

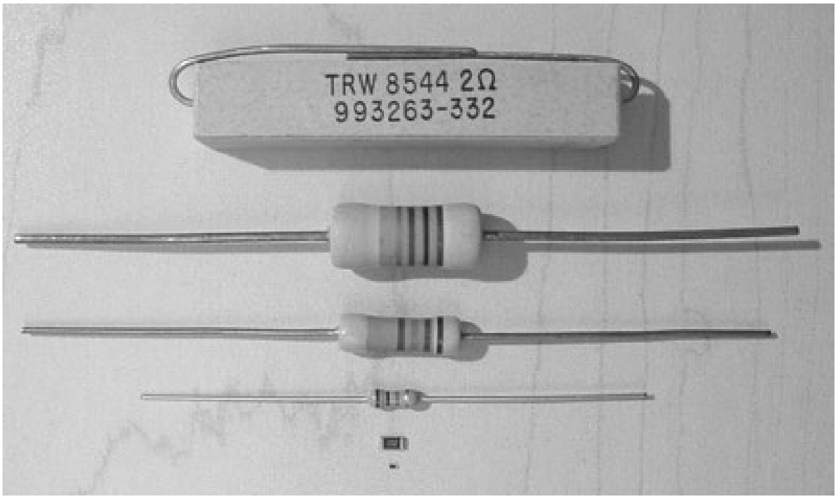

FIGURE 3-1 Variety of resistors.

middle terminal, called the *wiper*, can be adjusted anywhere along the resistance between the two outer terminals.

Potentiometers are used for controls of all types, such as volume and level controls. They can be rotary or sliding. They can have a shaft for a knob or a screwdriver slot for adjustment.

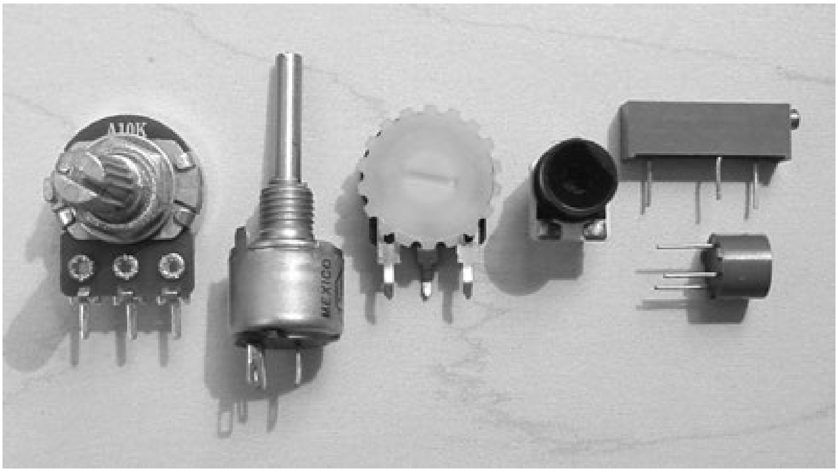

FIGURE 3-2 Variety of potentiometers.

To make sense of a schematic, you need to understand the symbols used to represent each of the types of common components.

Component Symbols

Symbols vary by country and manufacturer but will always be consistent within a schematic. The symbols in Fig. 3-12 are those normally used in the United States.

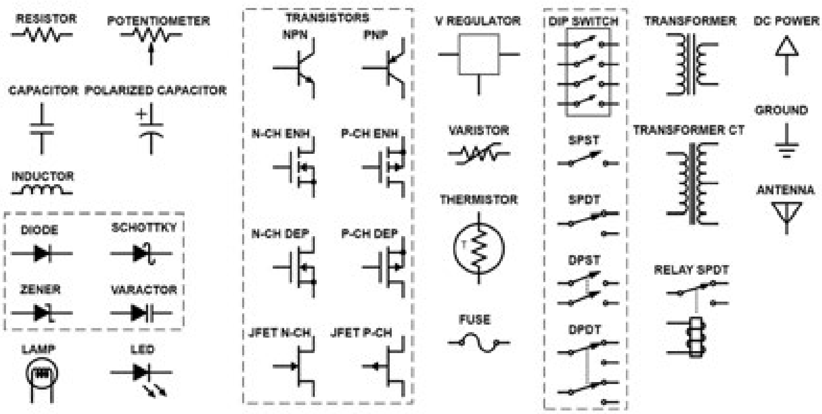

FIGURE 3-12 Component symbols.

There are two conventions for showing connections between wires (Fig. 3-13). The first convention uses a dot to show a connection. If two wires cross and there is no dot at the intersection, there is no connection.

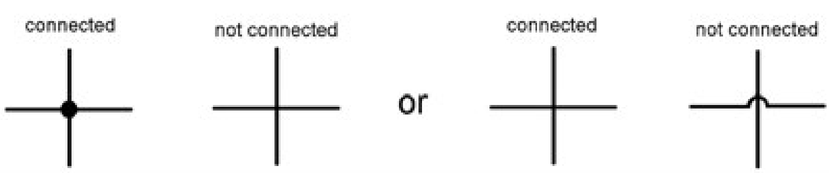

FIGURE 3-13 Wire connections in schematics.

The second convention uses half-circles to show no connection. If two wires cross and there is no half-circle, there is a connection.

Connections to ground and power can be shown using individual ground and power symbols for each circuit node, or they can be shown all wired together with a single ground or power symbol attached. The first method makes the diagram easier to comprehend. If the second method is used, you can take a black marker to highlight all the ground wiring and a red marker to highlight all the power wiring to improve clarity.

Introduction to Electricity

Having a basic understanding of electricity helps when it comes to repairing electronics, especially when troubleshooting is required to figure out what's wrong.

Basic Units of Electricity

The four basic units of electricity are voltage, current, resistance, and power. One way to help understand these electrical quantities is by thinking about water and plumbing (Table 3-1).

TABLE 3-1 Electrical Quantities versus Water Quantities

Electrical Quantity	Equivalent Water Quantity
Voltage (volts, V)	Water pressure (pounds per square inch)
Current (amperes or amps, A)	Water flow (gallons per minute)
Resistance (ohms, Ω)	Pipe resistance
Power (watts, W)	Pressure × flow (horsepower, hp)

Voltage and current are easiest to understand: voltage is like water pressure and current is like water flow.

Electrical resistance is analogous to a water pipe's resistance to flow. Imagine trying to fill a swimming pool from your hose spigot with a regular garden hose. Then think about how much longer it would take if the hose were the diameter of spaghetti. This is because of the higher resistance of the spaghetti-sized hose. In both cases, the water pressure (voltage) is the same, but in the case of the higher resistance, the flow (current) is reduced.

Ohm's Law

In electricity, this same relationship holds. It's called *Ohm's law*:

$$\text{Current} = \text{voltage}/\text{resistance}$$

This says that you can double the current (water flow) by doubling the voltage (water pressure) or by halving the resistance (pipe resistance). Ohm's law can be rearranged to calculate any of the three quantities if you know the other two.

Power Formulas

In electricity, power is calculated using this equation:

$$\text{Power} = \text{voltage} \times \text{current}$$

In terms of water, this means that you need both water pressure and flow to hose the mud off your car. Having lots of pressure but little flow is like trying to wash it with a squirt gun. Having lots of flow but little pressure is like gently pouring buckets of water over the car. You need pressure *and* flow to effectively wash your car.

When resistance is involved, this equation can be combined with Ohm's law and rearranged to produce two alternate equations for power:

$$\text{Power} = \text{voltage}^2/\text{resistance}$$

$$\text{Power} = \text{current}^2 \times \text{resistance}$$

These equations come in handy when you're trying to figure out the wattage rating you need for a resistor if you know the maximum voltage or current to which it will be subjected.

Batteries in Series

This is probably obvious to anyone who has replaced batteries in a flashlight, but the total voltage of batteries in series is the total of the voltages with DC. In contrast, most electronics need DC to work. Fortunately, it's practical to convert AC to DC with just a handful of parts.

WHY DO WE USE AC?

You might wonder why AC is used for providing power to our homes. The short answer is that AC makes it relatively easy to convert from one voltage to another by using transformers. Transformers don't work for DC.

Around the turn of the last century, when decisions were being made about power distribution over long distances, there were two competing factions. Thomas Edison was promoting a DC distribution system and Nikola Tesla an AC distribution system. The technically superior AC distribution prevailed.

By converting the AC to very high voltage for transmission (as high as a million volts), the same amount of power can be transmitted over thinner wires with lower power losses. That means cheaper electricity!

CHAPTER 4

Equipment and Supplies

Repairing electronics requires some specialized supplies and equipment. You may already have some of what you'll need. The usefulness of many of the items in this chapter depends on the type of repair work you'll be doing. Start small and build your equipment empire as you go.

The real value of this chapter is that it lets you discover something to make repairs faster, easier, cheaper, or better. This chapter is organized by basic supplies, hand tools, and equipment from basic to advanced.

Basic Supplies

Electrical Contact Cleaner Sprays

Electrical contact cleaner sprays are the closest thing I've found to a repair kit in a can. I've had great success in bringing equipment back to life by spraying switches, audio connectors, and potentiometers (pots) with the appropriate spray. I use CAIG DeoxIT D5 (Fig. 4-1) for switches and connectors and DeoxIT Fader F5 (Fig. 4-2) for pots.

Electrical contacts oxidize over time from exposure to the air, resulting in intermittent or bad connections. In mild cases, bad connections produce scratchy volume and tone controls in audio equipment. In more extreme cases, the equipment just doesn't work. I've had many pieces of test equipment that were completely nonfunctional until treated with contact spray.

The trick with contact sprays is to get the chemical into the contacts without getting it everywhere else. The CAIG FLEX-TIP helps with this. After spraying, work the switch or pot back and forth over its entire range many times to distribute the chemical and scrub the contacts. Clean up the excess and let dry.

FIGURE 4-1 CAIG DeoxIT D5. *(Courtesy of CAIG Laboratories, Inc.)*

FIGURE 4-2 CAIG DeoxIT Fader F5. *(Courtesy of CAIG Laboratories, Inc.)*

Air Duster

Air duster (Fig. 4-3) is like having compressed air in a can. It's useful for blowing dust and debris out of hard-to-reach crevices such as computer keyboards.

USE MAGNETS TO MAKE CLIP LEADS EVEN HANDIER

You can use magnets to hold the alligator clips of clip leads to flashlight battery terminals and other steel objects (Fig. 4-15). This solves the problem of not having a good place to clip onto. Put magnets between batteries to stack them when you need more voltage than a single cell provides. For this to work, you'll need strong, electrically conductive magnets. Neodymium magnets are a good choice. If the magnet doesn't look like metal, it's probably nonconductive and won't work. Keep a handful of suitable magnets with your clip leads.

FIGURE 4-15 Magnetic clip-lead trick.

Crimp Connectors

Crimp connectors (Fig. 4-16), also called *solderless connectors,* are commonly used in car stereo installation, where you may not want a hot soldering iron near leather upholstery. Crimp connectors also have their uses in general electronics repair, particularly if you want a ring or spade lug on the end of a wire.

WHAT'S THE DIFFERENCE BETWEEN JIS AND PHILIPS SCREWS?

In 1936, Henry F. Phillips patented the Phillips screw. It was a great solution for automobile production lines because it was designed to "cam-out" once a certain torque was reached, to prevent overtightening of the screw. Also, unlike slotted-head screws, the Phillips self-centering design allowed operators to engage the tip of the driver into the screw head quickly and easily.

In Japan, engineers developed their own cross-point design (Fig. 4-24). Like a Phillips screwdriver, the Japanese cross-point drivers have self-centering and quick tool-and-screw engagement. The key difference is that the JIS design allows torque and overtightening to be controlled by the operator, not the head of the screw.

FIGURE 4-24 JIS screw with dimple.

Because of the different profiles (Fig. 4-25), a conventional Phillips screwdriver tip won't fully seat in a JIS screw head. One reason is that the corner radius at the cross section on a JIS screw head is smaller than that of a Phillips tipped screwdriver. Also, most JIS screws have a shallower cavity and since a Phillips screwdriver has a longer tip design, it won't fit all the way into a JIS screw. As a result, a Phillips tip may not grip the sides of the JIS screw properly and will most likely cause the operator to damage the screw.

By contrast, a JIS screwdriver fits both JIS and Phillips screws perfectly. If you don't know what type of screw you've got, use a JIS driver because it's universal for both screw types.

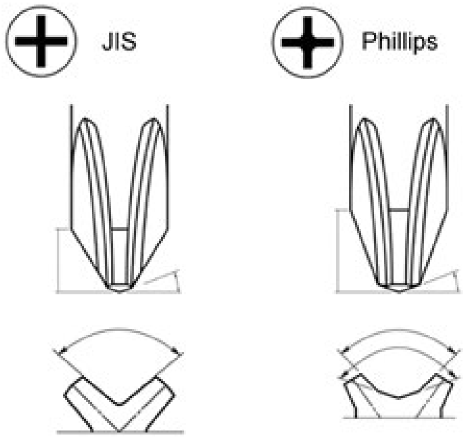

FIGURE 4-25 JIS versus Phillips screwdriver tips.

Security-Bit Set

Many electronic products such as video games and television set-top boxes use security screws to make them difficult to open. Security-bit sets (Fig. 4-26) contain a selection of bits to fit the most common security screw types, for use with a ratcheting screwdriver.

FIGURE 4-26 Klein 32-piece tamperproof bit set 32525. *(Courtesy of Klein Tools.)*

FIGURE 4-47 Peak Atlas ESR70. *(Courtesy of Peak Electronic Design Ltd.)*

	10V	16V	25V	35V	63V	160V	250V	400V	630V
4.7µF	42.00Ω	35.00Ω	29.00Ω	24.00Ω	20.00Ω	16.00Ω	13.00Ω	11.00Ω	8.5Ω
10µF	20.00Ω	16.00Ω	14.00Ω	11.00Ω	9.3Ω	7.7Ω	6.3Ω	5.3Ω	4.0Ω
22µF	9.0Ω	7.5Ω	6.2Ω	5.1Ω	4.2Ω	3.5Ω	2.9Ω	2.4Ω	1.8Ω
47µF	4.2Ω	3.5Ω	2.9Ω	2.4Ω	2.0Ω	1.60Ω	1.30Ω	1.10Ω	0.85Ω
100µF	2.0Ω	1.60Ω	1.40Ω	1.10Ω	0.93Ω	0.77Ω	0.63Ω	0.53Ω	0.40Ω
220µF	0.90Ω	0.75Ω	0.62Ω	0.51Ω	0.42Ω	0.35Ω	0.29Ω	0.24Ω	0.18Ω
470µF	0.42Ω	0.35Ω	0.29Ω	0.24Ω	0.20Ω	0.16Ω	0.13Ω	0.11Ω	0.09Ω
1000µF	0.20Ω	0.16Ω	0.14Ω	0.11Ω	0.09Ω	0.08Ω	0.06Ω	0.05Ω	0.04Ω
2200µF	0.09Ω	0.08Ω	0.06Ω	0.05Ω	0.04Ω	0.04Ω	0.03Ω	0.02Ω	0.02Ω
4700µF	0.04Ω	0.04Ω	0.03Ω	0.02Ω	0.02Ω	0.02Ω	0.01Ω	0.01Ω	0.01Ω
10000µF	0.02Ω	0.02Ω	0.01Ω	0.01Ω	0.01Ω	0.01Ω	0.01Ω	0.01Ω	0.00Ω
22000µF	0.01Ω	0.01Ω	0.01Ω	0.01Ω	0.00Ω	0.00Ω	0.00Ω	0.00Ω	0.00Ω

PEAK® electronic design ltd

Remember, lower ESR is better.

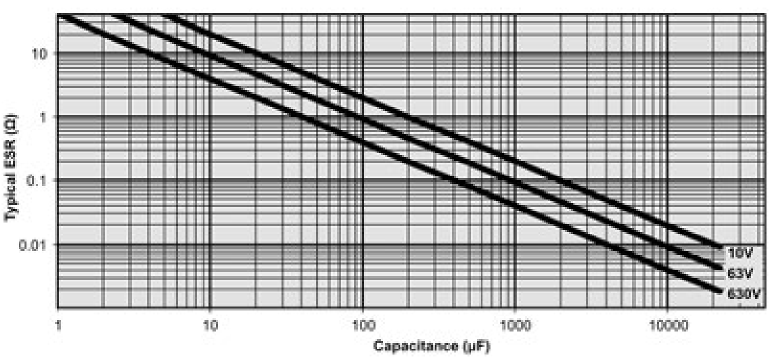

FIGURE 4-48 Peak Atlas ESR70 chart. *(Courtesy of Peak Electronic Design Ltd.)*

WHAT ABOUT PC OSCILLOSCOPES?

A PC oscilloscope (or USB oscilloscope) is generally a palm-sized device that connects to a personal computer via a USB cable. PC scopes use the display, computing power, and user-interface capabilities of the connected PC to reduce cost. Some PC scopes cost less than $100.

Despite the affordability of a PC scope, many users prefer a traditional oscilloscope. A few areas where inexpensive PC scopes may fall short include a lack of AC coupling mode, a lack of analog offset capability, and low resolution and bandwidth.

The PicoScope 2206B two-channel 50-MHz PC oscilloscope (Fig. 4-50) provides an AC coupling mode, analog offset capability, and a built-in function generator.

FIGURE 4-50 PicoScope 2206B two-channel 50-MHz PC oscilloscope. *(Image is copyrighted by and used with permission of Pico Technology.)*

CHAPTER 5

Soldering and Desoldering

Knowing how to solder and desolder is a necessary skill for electronics repair. With some knowledge and a little practice, everyone can learn to solder well enough for basic repair work. This chapter provides the knowledge. You will have to do the practicing on your own. Take advantage of the many tutorial videos online that show soldering and desoldering in action to hone your skills.

Soldering

Proper Tip Size and Temperature

Chapter 4 recommends an adjustable-temperature soldering station that can accommodate a range of tip sizes and styles (Fig. 5-1).

Choosing the right tip for the job is mostly a matter of size matching. This means using a needle-point tip when soldering tiny surface-mount chip resistors and caps and using a large tip when soldering physically large connections.

Soldering and desoldering operations subject components and the PC board to potentially damaging high temperatures. There are several ways to reduce the chances of causing damage. While it might seem like using a smaller tip and lower temperature setting would reduce the potential for damage, the opposite is usually true. To reduce the chance

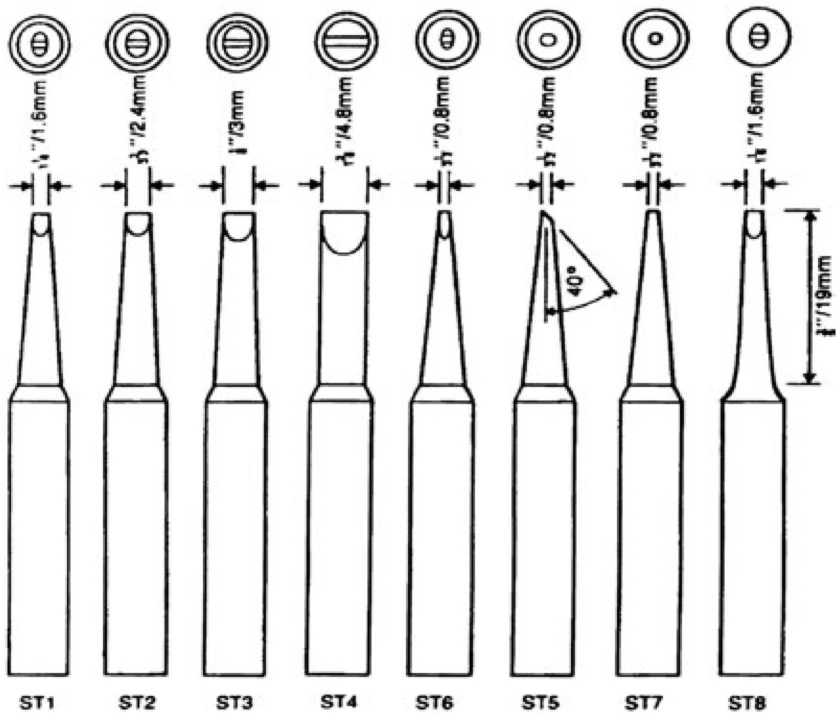

FIGURE 5-1 Weller ST Series tips for a WLC100 soldering station. *(Courtesy of Weller.)*

of damage, you want to reduce the time that you're heating the connection. If the tip is too small or the temperature setting is too low, you'll be spending too much time on the connection, allowing heat to flow where it's more likely to cause damage, such as into the body of a component. If you can't achieve a good solder joint in a few seconds, there's a good chance that you're using too small a tip or too low a temperature. Too low a temperature is easier to detect than too high, so work up to a temperature rather than down.

Use the Right Solder

Another factor in reducing the chances of heat damage is using the right solder. This means 63% tin and 37% lead (Sn63Pb37) with an activated rosin core (Fig. 5-2). Sn63Pb37 solder has the lowest melting point of the tin-lead alloys, and it is far lower than that of lead-free solders. Sn63Pb37 solder is suitable for soldering PC boards that use lead-free solder as well as leaded solder. An activated rosin core flux provides aggressive cleaning/wetting action to speed soldering.

TIP

Never use acid-core flux with electronics.

FIGURE 5-2 Kester 44 rosin-core solder 63/37, 0.031 inch. *(Courtesy of Kester.)*

WHAT'S SPECIAL ABOUT SN63PB37 SOLDER?

Many solder alloys are used to provide various desirable properties. Of all the alloys composed of only tin and lead, Sn63Pb37 solder is special. It is eutectic, which means that it melts and solidifies at a single temperature that's lower than the melting points of pure tin or pure lead or any other mixture of them (Fig. 5-3).

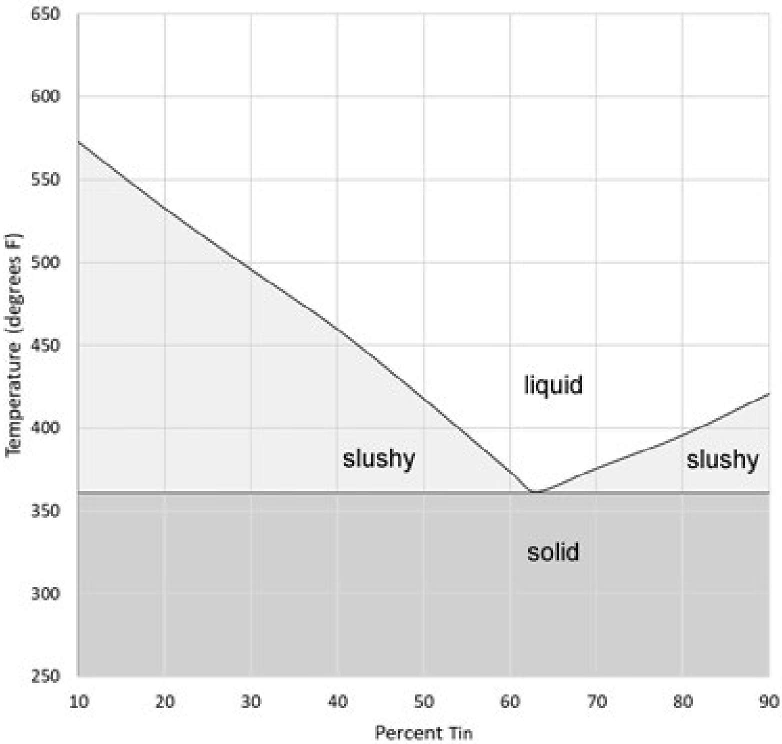

FIGURE 5-3 Phase diagram of tin-lead alloys.

For soldering, this lower temperature gives the advantage of reducing the likelihood of damaging electronic components during soldering. A second advantage is that it solidifies at a single temperature. The other alloys of tin and lead have a slushy phase as they cool from liquid to solid. If the connection is moved during this slushy phase, the result is a bad solder joint. Such joints have a dull appearance and are referred to as *cold solder joints*.

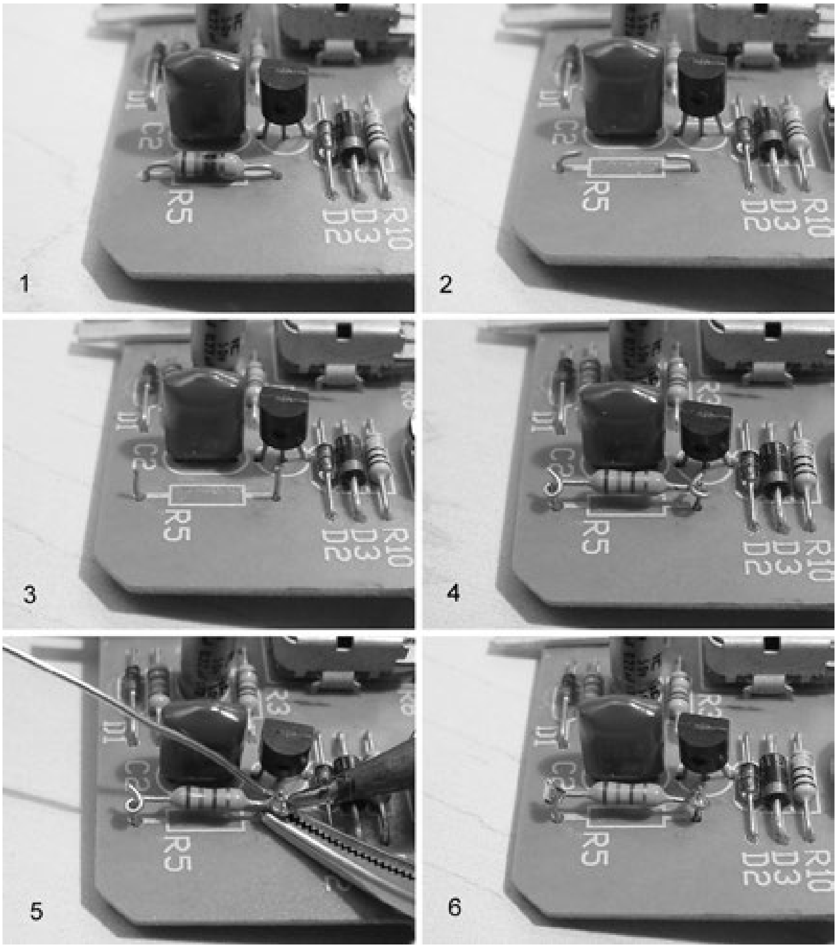

FIGURE 5-11 Clip instead of desolder: (1) bad resistor; (2) bad resistor with the body clipped out; (3) leads straightened; (4) new part in place (pre-tin the leads of the replacement part before putting in place, and twist the leads together if possible); (5) soldering in (try to minimize the time that you're heating the connection, and use a heat sink on the original leads if possible); (6) remove flux—repair complete.

cation. Like heat-sink compounds, thermal pads come in electrically nonconductive and conductive types. The electrically conductive pads provide better thermal performance, but they have the disadvantage of electrical conductivity.

FIGURE 5-15 Arctic thermal pad. *(Courtesy of Arctic www.arctic.ac.)*

The performance of pads is generally inferior to that of pastes, but the convenience of pads makes them a viable alternative. Expect to pay a premium for pads that outperform pastes.

COMPARING PADS AND PASTES

If you want to compare pastes and pads scientifically, compare their thermal conductivity specifications in watts per meter per kelvin (W/m-K). Higher numbers signify higher conductivity and are better. The thermal conductivity of a high-grade electrically non-

CHAPTER 6

Using Test Equipment

This chapter explains the basics of how to use the two most important pieces of test equipment for electronics repair: digital multimeters and oscilloscopes. Refer to Chapter 4 for what to look for when buying.

This chapter isn't intended to replace the operating manual of any equipment. It's intended to show what the equipment can be used for and its ease of use.

Using a Digital Multimeter

Most digital multimeters provide measurement capabilities for DC and AC volts, resistance (ohms), and DC and AC current (amps). Additional features and operation vary by manufacturer and model. I'll be using the Fluke 115 multimeter (Fig. 6-1) as an example to describe the most commonly performed measurements when repairing electronics.

General Measurement Procedure

The general procedure for most measurements is

1. Turn on the meter. (The Fluke 115 automatically turns on by selecting a measurement type.)

FIGURE 6-1 Fluke 115 multimeter.
(Reproduced with permission, Fluke Corporation.)

2. Select the measurement type (DC volts, AC volts, etc.) and measurement range. (On the Fluke 115, the knob, along with the yellow button, selects the measurement type. The 115 defaults to autorange. To enter the manual range mode, press the RANGE button repeatedly to select the desired range.)
3. Plug the probes into the multimeter jacks appropriate for the measurement. (For the Fluke 115, the black probe should be plugged into the COM jack and the red probe into the volt-ohm jack for all measurements except current.)
4. Touch the probe tips to the desired measurement points, and read the digital display on the meter.

Table 6-1 shows common examples of each measurement type.

TABLE 6-1 Examples of Multimeter Measurements

Measurement	Examples
DC volts	Checking whether an AC wall adapter is working Checking a battery
AC volts	Checking whether AC voltage is getting to an internal device point Checking whether a transformer is good
Resistance (ohms)	Checking whether a light bulb is good Measuring a resistor value
Continuity	Checking whether a fuse is good Checking whether a power cord is good Checking whether a switch is good Checking for shorts and opens on PC boards
DC current	Measuring how much DC current a device is using
AC current	Measuring how much AC current a device is using
Diode test	Checking whether a diode or transistor is good

CHECKING ALKALINE BATTERIES WITH A MULTIMETER

To check alkaline batteries with a multimeter, use the DC volts setting. The tricky part is knowing what voltage a good battery should be. Because you'll be measuring the battery without a load, the voltage should be higher than the nominal voltage. For example, fresh 1.5-volt batteries such as AAA, AA, C, and D cells should measure about 1.6 volts. If the voltage measures less than 1.2 volts, the battery should be replaced.

PIERCING PROBE TIP SUBSTITUTE

There are situations where you'd like to be able to probe a wire but don't have convenient access to either end. You can buy insulation-piercing probe tips, or you can use a sharp no. 11 X-Acto knife blade instead (Fig. 6-2).

FIGURE 6-2 X-Acto no. 11 blade as piercing probe tip.

Orient the blade in parallel with the wire so that the blade tip is most likely to slide between wire strands rather than cut into them. The hole in the blade is a convenient place to grip with your probe. Normally, a small cut in the insulation won't create any problems, but you can apply electrical tape over the cut if desired.

Continuity Mode

The continuity mode is a convenient method to check for opens and shorts. The meter beeps when low resistance is detected and is silent otherwise. (The Fluke 115 beeps when the resistance is less than 20 ohms.) The continuity mode is also useful for checking fuses, power cords, and switches.

Current Measurement

For routine repair work, current is less frequently measured than voltage or resistance. The measurement procedure is different, too. For one thing, you may need to plug your red probe into a different jack on the

CHAPTER 7

Part Identification, Testing, and Substitution

This chapter is about how to identify parts, tell whether they are working, and find a substitute, if needed. Unless stated otherwise, the procedures for checking parts in this chapter assume that the part is electrically out of circuit. This means that it is okay to have one leg of a component still soldered in. Chapter 8 covers in-circuit testing of components in detail.

Counterfeit and Off-Brand Parts

It's tempting to go with the cheapest price when shopping for replacement parts. But not all parts are created equal. Counterfeiting of semiconductors is surprisingly common. Experts have estimated that as many as 15 percent of all spare and replacement integrated circuits purchased by the Pentagon are counterfeit, and the military buys from reputable suppliers. E-waste is the source of many counterfeit and re-marked semiconductors. As with many counterfeit goods, a disproportionate number of fake chips are traced back to China.

Off-brand parts are often designed to look like their name-brand counterparts but don't have the same quality. Electrolytic and tantalum capacitors in particular should only be purchased from name-brand manufacturers.

Surface-Mount Device (SMD) Marking Codes

Surface-mount chip resistors don't have color bands; instead, the resistance value is printed on them using a numeric code. Very small chip resistors rarely have any markings—there just isn't enough space.

Three marking systems are in common use: the three-digit system, the four-digit system, and the EIA-96 system. The three- and four-digit systems work like the color-coding system for resistors with leads. The first two or three digits show the value, and the last digit is the multiplier. For example:

$$100 = 10 \times 10^0 \text{ ohms} = 10 \text{ ohms } (\textit{not } 100 \text{ ohms!})$$

$$4991 = 499 \times 10^1 \text{ ohms} = 4{,}990 \text{ ohms}$$

The letter "R" is used to indicate the position of a decimal point for resistance values lower than 10 ohms. The tolerance isn't indicated with the three- and four-digit systems.

The EIA-96 code is used for chip resistors with 1 percent tolerance. It uses a two-digit number to indicate the value (Table 7-2) followed by a letter to indicate the multiplier (Table 7-3). For example:

$$68\text{H} = 499 \times 10 \text{ ohms} = 4{,}990 \text{ ohms, 1 percent}$$

In addition to the three systems described, manufacturer-specific marking systems are also used. If the code doesn't jive with an ohmmeter reading, an alternate code may be the reason.

TABLE 7-2 EIA-96 Chip Resistor Number Code

Code	Value	Code	Value	Code	Value	Code	Value	Code	Value	Code	Value
01	100	17	147	33	215	49	316	65	464	81	681
02	102	18	150	34	221	50	324	66	475	82	698
03	105	19	154	35	226	51	332	67	487	83	715
04	107	20	158	36	232	52	340	68	499	84	732
05	110	21	162	37	237	53	348	69	511	85	750
06	113	22	165	38	243	54	357	70	523	86	768
07	115	23	169	39	249	55	365	71	536	87	787
08	118	24	174	40	255	56	374	72	549	88	806
09	121	25	178	41	261	57	383	73	562	89	825
10	124	26	182	42	267	58	392	74	576	90	845
11	127	27	187	43	274	59	402	75	590	91	866
12	130	28	191	44	280	60	412	76	604	92	887
13	133	29	196	45	287	61	422	77	619	93	909
14	137	30	200	46	294	62	432	78	634	94	931
15	140	31	205	47	301	63	442	79	649	95	953
16	143	32	210	48	309	64	453	80	665	96	976

TABLE 7-3 EIA-96 Chip Resistor Letter Code

Code	Multiplier
Z	0.001
Y or R	0.01
X or S	0.1
A	1
B or H	10
C	100
D	1,000
E	10,000
F	100,000

Discharging Electrolytic Capacitors

Electrolytic capacitors can store high voltages for minutes or even hours. Large-capacity high-voltage electrolytics are common in the power supply circuits of many products and pose a potential hazard. You can use a DC voltmeter to check for electrolytics with a stored charge. When working around them, it's a good idea to discharge any large capacitors measuring more than a few volts. The residual voltage can affect in-circuit measurements even if it's well below hazardous levels.

Some people use a screwdriver to electrically short the two terminals of a capacitor to discharge it, but this is a hazardous practice. It can produce a big spark and vaporize a chunk out of your screwdriver tip or capacitor terminal. In some circumstances, the capacitor can even explode. It's better to discharge a capacitor through a power resistor (Fig. 7-5).

A 47-ohm, 100-watt resistor is a good choice for many situations. It will safely discharge a 2,200-μF or smaller capacitor charged to 200 volts or less or a 4,700-μF or smaller capacitor charged to 50 volts or less. See the sidebar on the science of discharging capacitors for more information.

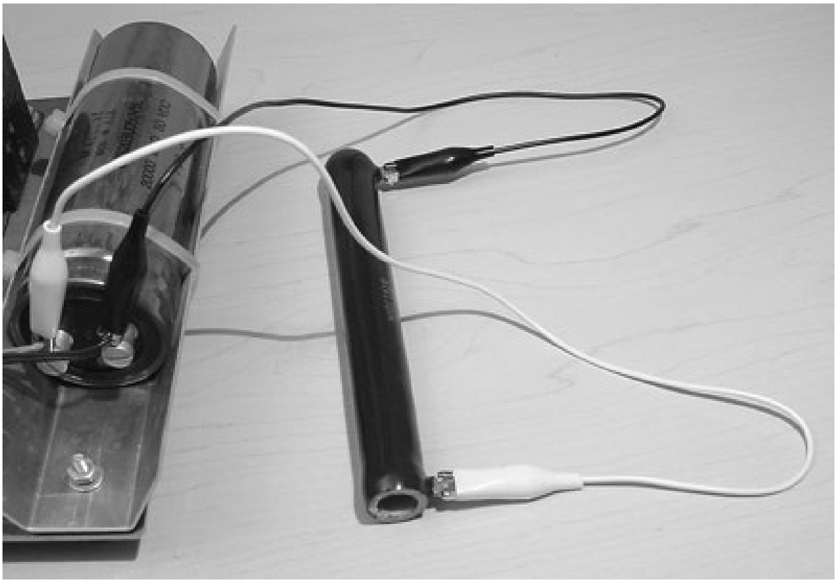

FIGURE 7-5 Discharging an electrolytic capacitor through a resistor.

If you substitute radial for axial parts (or vice versa), slide some heat-shrink tubing on the exposed leads to reduce the chances of an accidental short if something should touch the bare wires.

For electrolytics in switch-mode power supplies, always use low-ESR caps. Always order electrolytics with a 105°C temperature rating—they have better reliability. Be sure to order only name-brand parts from a reputable supplier. Name-brand electrolytic capacitor manufacturers include Cornell Dubilier, Nichicon, Panasonic, Rubycon, TDK, United Chemi-Con, and Vishay.

Observe the polarity markings on the capacitors and PC boards to make sure that you don't put a part in backwards. The negative terminals are usually indicated with a stripe or shaded area. Finally, consider proactively replacing other large-value caps in the circuit you're working on; they may be ready to fail.

WHAT'S SPECIAL ABOUT 105°C?

105°C is hotter than the boiling point of water. It's unlikely that your electrolytic capacitors will be used at or near this temperature, but you should always buy electrolytics rated at 105°C. The reason is that the temperature rating is an accurate indicator of electrolytic lifespan.

Within limits, the life of a capacitor doubles for every 10°Celsius decrease in operating temperature. Equivalently, the life of a capacitor doubles for every 10°Celsius increase in temperature rating. Caps rated for 105°C can be expected to last about four times longer than equivalent caps rated at 85°C.

Tantalum Capacitors

Solid tantalum through-hole capacitors are pearl or teardrop shaped and are polarized. Surface-mount versions are common and can be identified because they don't look like a can, and they have a polarity indication. Tantalum caps usually have their positive terminals marked with a plus (+) sign. Because electrolytics have their negative terminals marked with a minus (–) sign, this can cause dangerous confusion.

Typical values cover the range from 0.1 to 1,000 µF. Their capacitance and voltage values may be printed on them or color-coded. Table 7-6 shows the color code for through-hole parts.

TABLE 7-6 Tantalum Capacitor Color Code

Top = First Digit	**Middle = Second Digit**	**Dot = Multiplier**	**Bottom = Voltage**
Black = 0	Black = 0	Black = ×1 µF	Black = 10 volts
Brown = 1	Brown = 1	Brown = ×10 µF	—
Red = 2	Red = 2	Red = ×100 µF	—
Orange = 3	Orange = 3	—	—
Yellow = 4	Yellow = 4	—	Yellow = 6.3 volts
Green = 5	Green = 5	—	Green = 16 volts
Blue = 6	Blue = 6	—	Blue = 20 volts
Violet = 7	Violet = 7	—	—
Gray = 8	Gray = 8	Gray = ×0.01 µF	Gray = 25 volts
White = 9	White = 9	White = ×0.1 µF	White = 3 volts
—	—	—	Pink = 35 volts

Tantalum caps have much better high-frequency performance than electrolytics and don't degrade over time, but they are extremely sensitive to overvoltage or reverse voltage conditions, which can destroy them. Tantalums tend to fail at turn-on. They almost always fail as a short circuit. Combined with the fact that tantalums are usually used for power supply bypassing, this means that if a product fails at turn-on with symptoms that a power supply is down, a tantalum cap is a prime suspect. *Bypassing* is an electronics term that means using a capacitor connected between a point in a circuit (normally a DC power supply) and ground to "bypass" high-frequency noise.

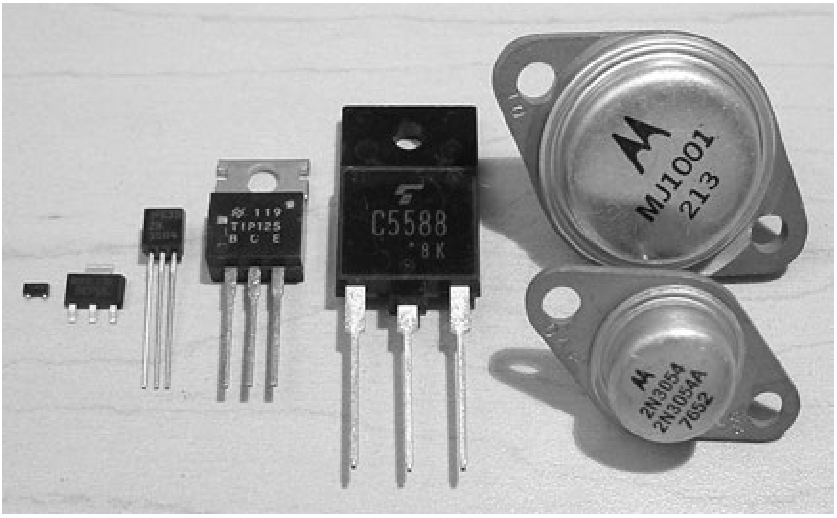

FIGURE 7-8 Variety of transistors.

Transistor Packages

Transistors come in many different through-hole and surface-mount packages (Fig. 7-9). Sometimes the same transistor is offered with more than one packaging option. Larger packages provide better heat dissipation, either directly to the air or through a heat sink. The order of the pins can change with the package option, too.

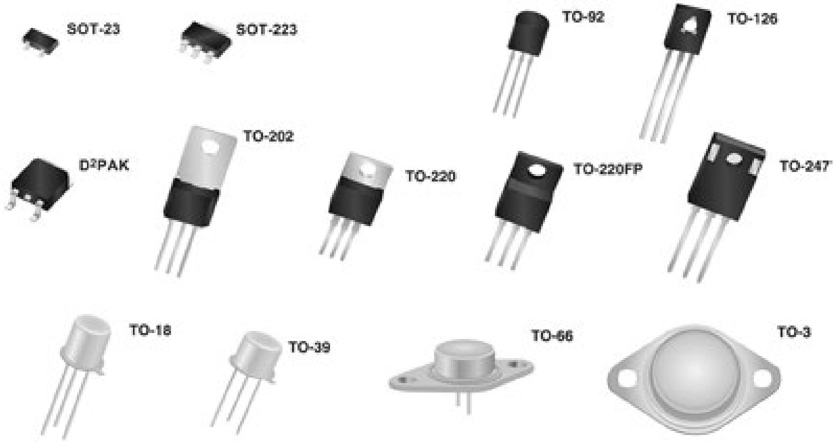

FIGURE 7-9 Transistor packages. *(Courtesy of Central Semiconductor Corp.)*

There are many types of transistors: NPN, PNP, and n-channel and p-channel MOSFETs (metal-oxide-semiconductor field-effect transistors), to name a few. The three pins of bipolar transistors (NPN or PNP) are called the *base*, *emitter*, and *collector*. The three pins of MOSFETs are called the *gate*, *source*, and *drain*. The most common types can be checked out of circuit using a multimeter. See the following sidebars for the procedures.

Transistor Failure Modes

Bipolar transistors usually fail with a shorted base to emitter or collector to emitter. MOSFETs usually fail with a shorted drain to gate or drain to source. If a MOSFET fails with a shorted drain to gate, this puts the drain voltage onto the gate, where it's likely to damage the drive circuitry, so the drive circuitry should be checked when replacing a MOSFET with shorted drain to gate. MOSFET failures tend to be dramatic, so usually if they look okay, they are.

TESTING BIPOLAR TRANSISTORS

NPN and PNP transistors can be checked out of circuit using the diode test feature of a multimeter. Table 7-10 shows the diode test results for good NPN and PNP transistors. Connect the meter probes as shown in the table, and compare your results against those in the appropriate transistor type column.

TABLE 7-10 Testing Bipolar Transistors

Positive Lead (Red)	Negative Lead (Black)	NPN Diode Test	PNP Diode Test
Base	Emitter	~0.6 volt	Over limit (OL)
Base	Collector	~0.6 volt	OL
Emitter	Base	OL	~0.6 volt
Collector	Base	OL	~0.6 volt
Emitter	Collector	OL	OL
Collector	Emitter	OL	OL

If you don't know whether a transistor is NPN or PNP or don't know which pins are which, you can still perform the test. Just try all six combinations of meter probe connections to pins of the device and see whether two of the results are about 0.6 volt and the rest are over limit (OL).

Note: This test verifies that the transistor is not shorted or open. It does not guarantee that the transistor is operating within all its design parameters.

TESTING ENHANCEMENT-MODE MOSFETS

n-Channel and p-channel enhancement-mode MOSFETs can be checked out of circuit using this procedure. Depletion-mode MOSFETS cannot be checked with this procedure but are rarely used in circuits.

Safety Note: MOSFETs are highly sensitive to ESD. ESD-safe practices should be used when handling them, such as using an antistatic mat and wrist strap. Use solder wick or an ESD-safe solder sucker when removing MOSFETs from circuit boards.

This procedure uses the diode test feature of a multimeter but requires that the open-circuit voltage applied by the meter is high enough to partially turn on the MOSFET. Meters that use a low open-circuit voltage (such as 1.5 volts) will not work. Open-circuit voltages of 3–4 volts are good.

You'll need to know which pins are the gate, source, and drain to do the test, so it's helpful to first identify the part. Most MOSFETs in a TO-220 package have the leads in gate, drain, source (GDS) order left to right.

For n-Channel Enhancement-Mode MOSFETs

1. Connect the meter's negative lead (black) to the MOSFET's source pin.
2. Use a clip lead to momentarily short the MOSFET's gate pin to source pin. This turns the transistor off. The MOSFET's gate capacitance is sufficient to hold the voltage afterward.

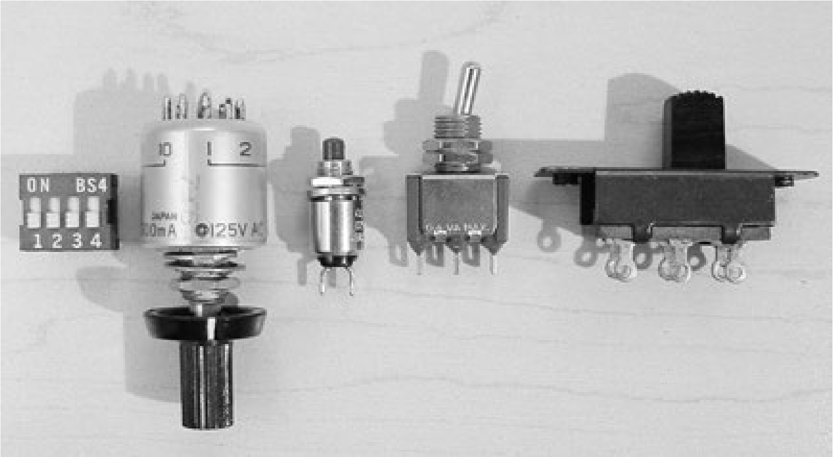

FIGURE 7-17 Variety of switches: DIP, rotary, pushbutton, SPDT, DPDT.

TABLE 7-12 Switch Parameters

Parameter	Examples
Type	Toggle, pushbutton, rocker, rotary, slide
Mounting style	Panel mount, through-hole, surface mount
Contact form	SPST, SPDT, DPDT
Switch function	ON-ON, ON-OFF-MOM, (ON)-NONE-(ON)
Termination style	PC pin, solder lug, screw
Illumination	None, LED, incandescent, neon
Current rating	1 amp, 10 amp
Voltage rating	120 VAC, 12 VDC

Pole and Throw Terminology

A switch must have at least two terminals, but often switches have three, six, or even more terminals. The connections between all those terminals are described using poles and throws (Fig. 7-18). Poles are the number of subswitches the switch contains. Throws are the number of wired positions each subswitch provides.

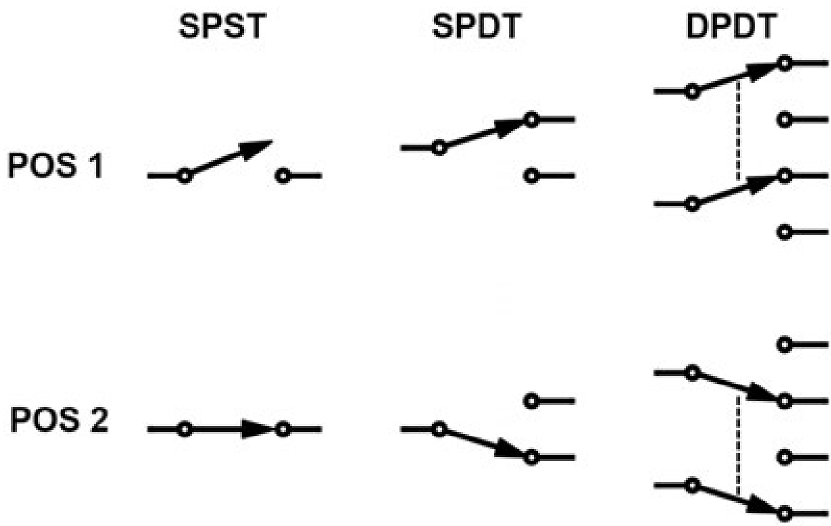

FIGURE 7-18 Pole and throw terminology: SPST, SPDT, DPDT.

A single-pole, single-throw (SPST) switch is as simple as it gets. It's got a single subswitch with a single wired position. SPST switches have two terminals that are either connected (on) or not (off) depending on which of the two switch positions is selected.

Next in the lineup is a single-pole, double-throw (SPDT) switch. It has a single subswitch with two wired positions. SPDT switches have three terminals, and the center terminal is either connected to one or the other outer terminal depending on which of the two switch positions is selected. It can be wired as an on-off switch by not using one of the outer terminals.

Double-pole, double-throw (DPDT) switches have two subswitches, each with two wired positions. These have six terminals arranged in a 2 × 3 grid, and the center terminal of each subswitch is either connected to one or the other outer terminal depending on which of the two switch positions is selected.

Switches with four poles and three throws (4P3T) and even higher exist. When replacing any switch beyond SPST, it's important to wire the replacement the same way as the original. Take a picture with your phone beforehand as an insurance policy.

AC Adapters

AC adapters (Fig. 7-23), also known as *wall warts, wall chargers,* or *power bricks*, have become ubiquitous in electronics. This section will tell you how to test them, repair them, and find a substitute if necessary.

FIGURE 7-23 AC adapters.

AC Adapter Basics

If a product appears powerless, your first suspect (after making sure that it's plugged in and turned on) should be the AC adapter. Most AC adapters provide a DC output, but there are a few that provide an AC output.

There are two types of DC output adapters: unregulated and regulated. Unregulated adapters are just a transformer with diode rectifier and maybe an electrolytic capacitor. The output voltage of these changes dramatically depending on how much current is being drawn. A 12-volt unregulated adapter might measure 12 volts at the rated current and 15 volts or more with no load. Regulated adapters can be linear or switch mode. Almost all regulated adapters nowadays are switch mode. These are identifiable by their comparatively small size, light weight, and wide

AC Adapter Substitution

When searching for a substitute AC adapter, you'll need to match the voltage type (AC or DC), voltage, current, and connector. If the original adapter was regulated, the substitute should be too. Unregulated DC adapters may be replaced with regulated or unregulated DC adapters.

The current rating of the substitute adapter depends on the type of adapter. Table 7-14 shows the acceptable range. With unregulated adapters, the voltage changes with load, and using an adapter with a much larger current rating runs the risk of providing an output voltage that's too high. With regulated adapters, the voltage remains the same with load, and there's no overvoltage issue with higher current specifications. The only danger in using an adapter with a lot more current capacity than you need is if there's a short circuit in the device. The extra current can cause much more damage.

TABLE 7-14 AC Adapter Substitution Current Rating

Original Adapter	Substitute Adapter	Current Rating (Original = 100%)
AC	AC	100–150%*
DC unregulated	DC unregulated	100–150%*
DC unregulated	DC regulated	100% or higher
DC regulated	DC unregulated	n/a
DC regulated	DC regulated	100% or higher

**Assumes 25 percent transformer regulation producing 8 percent voltage increase.*

Sometimes the biggest challenge in finding a substitute adapter is finding one with the right power connector dimensions and polarity. Frequently, the full connector specs aren't provided by the seller. If you find an AC adapter that meets your electrical requirements, you can always solder on a replacement DC power connector that meets your connector requirements. See the sidebar "Replacing DC Power Connectors."

CHAPTER 8

General Repairs and Troubleshooting

This chapter provides repair guidance that can be applied to any electronic device. Chapter 9 provides additional information for frequently repaired devices.

Is It Worth Fixing?

There's no simple answer to whether or not something is worth fixing. It usually makes sense to at least check for an easy repair. Take off the cover and see what's inside. The problem may be obvious, and the repair may take very little effort.

Even if a device isn't worth fixing, it may have parts value. There's probably somebody looking for a part that's still good on your device. It could be a remote control, stand, set of knobs or feet, AC adapter, or electronic subassembly.

Poor Candidates for Repair

Some repairs are notoriously bad investments of your time. These include

- Lightning-damaged equipment
- Liquid-damaged/submerged equipment

All the damage done by lightning may not show up right away. The high voltage induced by nearby lightning strikes into AC power and cable lines (TV, internet, phone) can weaken or degrade semiconductors so that they're poised for future failure. You might think you've fixed a lightning-damaged device, but you'll be working on it again soon.

It's surprising how much damage liquids can cause to multilayer PC boards with surface-mounted microelectronics, even ordinary drinking water. Soda and saltwater are worse. If the power was on when the spill occurred, the damage is multiplied. If a simple cleanup of a spill doesn't fix the problem, a quick repair is unlikely.

How Did It Break?

Knowing how a device broke provides valuable clues about what's wrong.

- As mentioned earlier, devices damaged during a thunderstorm or from liquids are poor candidates for repair.
- Devices with problems that come and go are especially challenging. See the section "Intermittent Problems" later in this chapter.
- Did the problem gradually get worse? Failing electrolytic capacitors are the leading cause of gradually worsening symptoms. Test them with an ESR meter or the parallel-cap technique (explained later in this chapter).
- Devices damaged from a drop may have obvious damage such as a cracked screen, or they may have hidden damage. See the sections "Taking It Apart" and "Components with a Hairline Crack" later in this chapter.

First Things to Check

Before getting out the tools and taking the device apart, perform a few basic checks first.

Is It Getting Power?

Check to make sure that the power cord is firmly plugged into the device and the wall. If there's an outlet strip involved, make sure that it is plugged in and turned on. Make sure that the wall outlet has power by plugging something else into it as a test. Sometimes the top outlet is controlled by a wall switch and the bottom one isn't. If an AC adapter is used, make sure that it is the right AC adapter for that device.

For battery-operated devices, make sure that the batteries are good and are installed correctly. Usually, the springs go to the negative battery terminals, but not always. If the terminals are corroded, they may not be making good electrical contact with the batteries. Clean them with a pencil eraser or vinegar and cotton swabs.

Check the Fuse

If there's an easily accessible fuse holder, check the fuse.

Unplug for a Few Minutes

Microprocessors (now in almost everything) can get off in the weeds from power spikes and other conditions and make the device unresponsive. Unplug it for a few minutes; then plug it back in and see if it works.

Factory Reset

More complex electronics such as smart TVs have different levels of reset. When unplugging for a minute doesn't fix a problem, perform a factory reset. Factory reset for TVs is usually located in one of the menus under Settings, System, or Support. Consult the owner's manual or internet for how to perform a factory reset on other devices.

Taking It Apart

Sometimes taking a device apart is a bigger challenge than fixing what's broken. This section gives some suggestions to minimize damage while taking things apart and getting them back together again.

Screws under Feet and Labels

Hiding screws under feet is common. Feet may be adhesive backed or push-in. Usually, screws under feet are an all-or-nothing proposition—you won't find just one.

Another popular place to hide screws is beneath adhesive labels. This acts as a tamper-evident seal for manufacturers. The way to check for these is to run your finger over the entire sticker surface, applying pressure, and feeling for round indentations. If you find one, you have the choice of running an X-Acto knife around the inside of the hole to remove a circle of sticker or using a heat gun (or hair dryer) to warm up the sticker and carefully peeling it back.

MAKE YOUR SCREWDRIVERS MORE ATTRACTIVE

A magnetic screwdriver set saves time and frustration when you are disassembling and reassembling equipment held together with screws. This is especially true when screws are at the bottom of deep access holes. An alternative is to make the screwdrivers you already own magnetic.

The Klein Tools MAG2 Magnetizer (Fig. 8-1) works by swiping the tool shaft through the magnetizing hole in the magnetizer. There are also demagnetizer holes for demagnetizing tools.

FIGURE 8-1 Klein Tools MAG2 Magnetizer.
(Courtesy of Klein Tools.)

Hidden Tabs

Hidden tabs are commonly used to hold two halves of plastic cases together. Examples include remote controls, laptops, routers, and phones. Most devices that use hidden tabs also use screws, so if a case seems like it's not coming apart at a certain spot, there's probably a missed screw somewhere close by. Prying apart cases requires finesse to avoid damage. For phones and tablets, you can buy a pry tool set to make the job easier (Fig. 8-2). If you don't have a pry tool set, credit cards and guitar picks come in handy. There are plenty of YouTube videos showing how to take any popular phone apart.

FIGURE 8-2 iFixit prying and opening tool assortment. *(Courtesy of iFixit.)*

Cutting It Apart

Some plastic cases are ultrasonically welded together and are not made to be taken apart. A prime example is some AC adapters. For such items, you'll need to cut them apart along the seams. Tools that are useful for this job are a mini hacksaw (Fig. 8-3), razor saw (Fig. 8-4), and a hot knife tip for a soldering iron (Fig. 8-5). Care must be taken to avoid cutting too far into the case and damaging internal components. When using a hot

TABLE 8-1 Board Connector Disassembly

Connector	Take Apart	Put Together
Front flip actuator	Flip the actuator up with your fingernail. Angle the flat cable slightly to allow the two ears to clear the connector, and pull out (Fig. 8-9).	Make sure that the actuator is up. Angle the flat cable slightly to allow the two ears to clear the connector, and insert. Flip the actuator down.
Back flip actuator	Flip the actuator up with your fingernail. Angle the flat cable slightly to allow the two ears to clear the connector, and pull out (Fig. 8-10).	Make sure that the actuator is up. Angle the flat cable slightly to allow the two ears to clear the connector, and insert. Flip the actuator down.
Slider	Slide the plastic retaining bar to its out position by alternately working the two sides of the bar. Pull the flat cable out (Fig. 8-11).	Make sure that the plastic retaining bar is in its out position. Fully insert the flat cable. Slide the plastic retaining bar to its in position.
Non–ZIF	Grasp the flat cable near the connector. Pull the flat cable out (Fig. 8-12).	Grasp the flat cable near the end. Firmly push the flat cable into the connector until it's fully seated.
Tabbed	Squeeze the tab at the back, and pull the cable out (Fig. 8-13).	Insert the cable firmly until the tab engages.

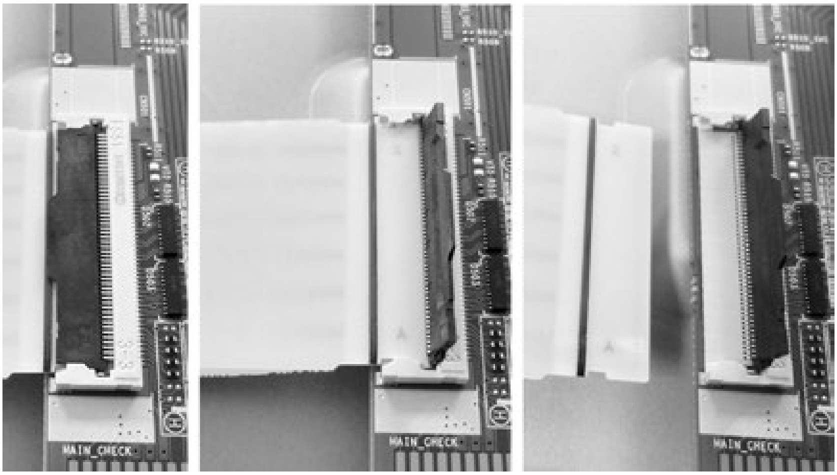

FIGURE 8-9 Releasing front flip actuator connector.

Visual Inspection

Visual inspection can go a long way toward revealing the source of a problem. This section describes what to look for and what it means.

Bulging or Leaking Electrolytic Capacitors

Failed electrolytic capacitors are a top cause of problems in electronics. Look for electrolytic caps that are bulging, have split tops, or any signs of leakage (Fig. 8-14). If you find any, they're bad. Caps that look fine can also be bad, so if you find a bad one, check others that look good with an ESR or capacitance meter. If the device only has a few electrolytics, consider replacing all of them preemptively. See Chapter 7 for guidance on replacement parts.

FIGURE 8-14 Bulging electrolytic capacitor.

STRESS AND THE COEFFICIENT OF THERMAL EXPANSION

The reason temperature cycles cause mechanical stress failures in electronics is the coefficient of thermal expansion. Most materials expand as they get warmer, but the coefficient of thermal expansion is different for different materials. This means that as the temperature changes, some things expand more than others. A prime example is connectors and PC boards.

If a 20-pin connector and the section of a PC board to which it mounts are the same size at room temperature, they may want to expand to different sizes after the device has warmed up. This creates stress that over thousands of temperature cycles causes a connection failure at a solder joint. The effect is magnified with larger components such as connectors, ICs, metal shields, and heat sinks.

To minimize these problems, diligent circuit designers try to specify PC boards and components that have low or matching coefficients of thermal expansion.

I/O Components

I/O components are the input and output connectors and their associated electronic components. They're subjected to physical abuse whenever something is plugged into or removed from them. They're also subjected to ESD from the people who plug things in.

If a problem is related to an input or output feature, inspect closely for broken connections at the associated connector pads and cracked components nearby.

Mechanical Components

Mechanical components such as switches, relays, pots, and connectors are frequent causes of problems because they are sensitive to dirt, contamination, moisture, wear, electrical arcing, and oxidation. Contact cleaners can often renew switches, connectors, and pots. Reseating connectors (taking them apart and putting them back together) can fix a bad or intermittent connection.

Intermittent Problems

Intermittent problems come and go. They're especially challenging to fix because you can't find the problem when the device is working properly.

Get the Problem to Show Up

The first step in fixing intermittent problems is trying to get the problem to reliably show up. This gives you a way to work on the problem and a way to know when it's fixed. It also provides clues about what's broken. Observe the conditions that make the problem appear, such as the temperature of the room, how long the device has been on, mode of operation, and so on.

Here are some things to try with the cover off and the product operating. Use caution. If working near potentially lethal voltages, use an isolation transformer, and keep one hand behind your back.

- Wiggle wires, cables, and connectors.
- Try different product orientations where appropriate.
- Press on the circuit board in various locations using an insulated object such as a plastic pen.
- Use a heat gun to selectively heat components.
- Use freeze mist to selectively freeze components.

Likely Suspects for Intermittent Problems

Table 8-2 shows some likely suspects for intermittent problems and recommended actions.

The Joy of Sets

Sometimes the circuit you're working on has a duplicate you can use as a reference. Common examples are audio equipment with left and right channels and dual power supplies. Or you may have access to multiple units of the same model, one working and one not. This gives you the ability to perform in-circuit testing to a higher level. It no longer matters if a resistor's reading is affected by other circuit components; it should measure the same as its twin.

When using this technique,

- The polarity of your multimeter leads must be the same for both measurements.
- Both channels must have the same settings and loads.
- Differences may not be from the component you're measuring.

Out of circuit resistor measurements are insensitive to which side the red or black probes are connected to, but that's not true for in-circuit measurements, where there could be a diode or transistor connected to the resistor.

All the settings and external connections must be the same for both measurements or you'll be comparing apples to oranges. For stereo receivers, set the balance control to the center position.

If you measure a component difference between the bad and good channels, keep in mind that it might not be from the part you're measuring. It might be due to another part that's affecting your measurement. Measure the suspect component out of circuit or perform additional measurements on nearby components to determine the culprit.

Power the Circuit

Applying power to the circuit allows better in-circuit testing of transistors, Zener diodes, voltage regulators, and transformers (Table 8-4).

TABLE 8-4 Powered Component Measurement

Component	Comment
Bipolar transistors	Check for greater than 0.7 volts between base and emitter and for the same voltage on any two terminals.
Zener diodes	In voltage references and regulators, DC voltage across diode should be close to the Zener voltage.
Voltage regulators	See Chapter 7.
Transformers	See Chapter 7.

SAFETY TIP

Never work on powered circuits unless you know and use safe working practices. Many circuits that derive power from 120 VAC, and some that don't, contain lethal voltages as well as other hazards. If you are working near potentially lethal voltages, use an isolation transformer, and keep one hand behind your back.

Bipolar Transistors

Powering a device often lets you detect transistor failures in-circuit. Testing transistor circuits is more advanced and is covered in the section "Troubleshooting." The following test is for bipolar (NPN or PNP) transistors. Use your multimeter to measure the DC voltages of the three transistor terminals.

- More than an approximately 0.7-volt difference between base and emitter voltages may indicate an open-circuit base-emitter junction.
- The same voltage on two or more terminals may indicate shorted junctions.

While the same voltage on multiple terminals can indicate a bad transistor, it can also be caused by other circuit conditions.

Zener Diodes

Zener diodes are useful for voltage references, power supply regulators, and overvoltage protection circuits. Zeners usually fail as a short, which is easily detected in-circuit with the diode test feature of a multimeter. To see if a Zener diode is working properly in a voltage reference or power supply regulator circuit, measure the DC voltage across it. It should be approximately equal to its specified Zener voltage. For overvoltage protection circuits, the DC voltage should be less than the Zener voltage.

PARALLEL-CAP TECHNIQUE

If you don't have an ESR meter or capacitance meter, detecting bad electrolytic caps is difficult if there are no visible signs of failure such as a bulging top or leakage.

One option is to measure the AC ripple voltage across each cap with the circuit powered, but you may not know what an acceptable AC level is. Another option is the parallel-cap technique (Fig. 8-17). The idea is to temporarily connect a good capacitor across the suspect capacitor to see if the problem goes away. Connect the cap using clip leads or by tack soldering. (Tack soldering just means a temporary connection to hold a component in place.) The power should be off while making the connection. When using this technique, follow these rules:

- The parallel-cap polarity must match the suspect cap (get it wrong and it could explode).
- The parallel-cap voltage rating must equal or exceed that of the suspect cap.
- The parallel-cap capacitance should be about the same as that of the suspect cap.
- For capacitances larger than 100 μF, safely discharge the suspect cap before connecting the parallel cap.

It's handy to have a stockpile of higher-voltage electrolytic caps of various values for this technique. If the parallel capacitance value is less than about half that of the suspect cap, it may not be enough to affect the problem. If it's more than the original, it could cause circuit malfunctions.

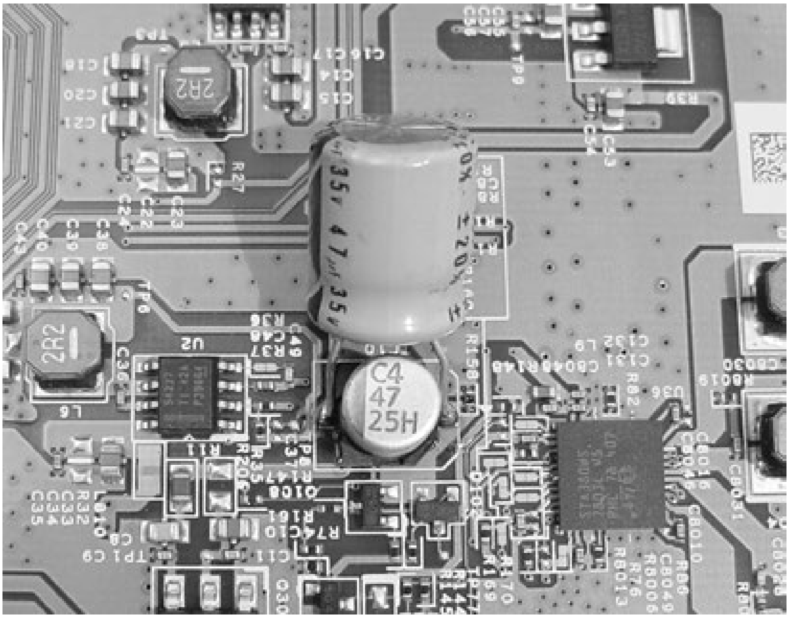

FIGURE 8-17 Parallel-cap technique.

More Joy of Sets

With the power turned on, having a duplicate circuit for reference provides even more clues about what's broken. But aimlessly measuring the AC and DC voltages of every component to compare against its twin is not a good strategy. Use this technique to measure and compare the voltages of highly suspected parts. Then it's time to move on to troubleshooting.

Troubleshooting

Up to this point in this book, the focus has been on detecting component failure. The advantage of this approach is that it requires little or no understanding of how a circuit or system works. For more complex problems, though, using component failure detection is like duck hunting blindfolded.

What Is Troubleshooting?

Troubleshooting is performing a series of experiments based on knowledge of how a circuit or system works. The goal is to find and fix the problem. Entire books have been written on troubleshooting electronics. I'll try to condense the subject to its essence.

Before troubleshooting, start every repair project by checking the obvious and easy stuff first. This includes the component failure detection methods described previously.

Understand the System

If you're going to be performing experiments based on knowledge of how a circuit or system works, the first step is to gain that knowledge. Table 8-5 shows some top resources.

TABLE 8-5 Resources for Understanding the System

Resource	Comments
Service manual	Single best resource when you can find it
IC datasheet	Useful when problem centers around an IC
YouTube videos	Great for common problems on popular devices
Repair forums	Can ask questions
iFixit.com	One-stop online repair resource

The internet is where you'll find most resources to improve your knowledge of a particular device. When it's available, the single most useful resource is a service manual. Comprehensive service manuals contain descriptions of how a device works, circuit diagrams, parts information, and troubleshooting guidance. Sometimes a service manual is available for free downloading; other times you'll have to pay for an electronic or paper manual. If you can't find a service manual for

This shows that the voltage gain is the ratio of –Rc/Re. If Rc is five times the value of Re, the amplifier would have a voltage gain of –5, and the AC output would be 500 mV for a 100-mV input. The minus sign means that the output waveform is inverted (upside down) with respect to the input.

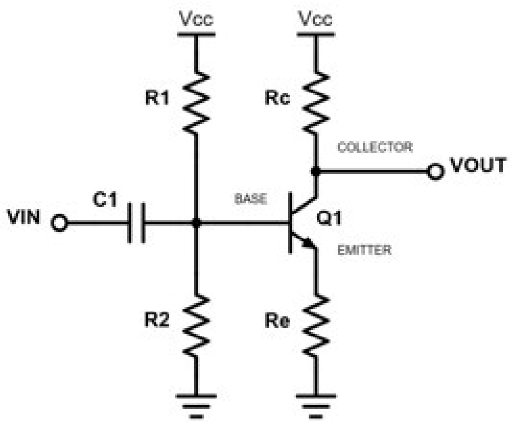

FIGURE 8-20 Basic transistor amplifier circuit.

Keeping a Repair Log

At some point, I realized that many of my new repairs were duplicates of past repairs. I would sometimes rediagnose a problem I had fixed before, not remembering the fix. That's when I decided to keep a repair log.

Keeping a repair log can be as simple as you want it to be. You can use a spiral notebook or Excel spreadsheet. It's a small investment in time that can pay back in a single duplicate repair. An excerpt of my repair log is shown in Table 8-6.

TABLE 8-6 Repair Log Example

Date	Owner	Type	Model	Problem	Parts	Notes
x/x/xx	x	dsl modem	2wire 2701hg-b	dead	1000µF 16v 105c low esr 470µF 10v 105c	Lytics inside wall wart were bulging and measured near zero.
x/x/xx	x	tv	insignia ns-lcd37-09 ver a	dead	audio video main board CBPF8Z-5KQ1 715T2830-1	LED turned blue and supplies came up, but no pix, sound or back-light.
x/x/xx	x	speakers	bose 501 series iv	bad woofers	bose 111791 re-placed with Parts Express 295-315	damaged voice coil. Replaced woofers with Day-ton DC250-8 10".
x/x/xx	x	carpia-giani cpu module		level sensor error		Bad solder on pin.
x/x/xx	x	computer	imac g5	intermit-tent won't turn on	9 lytics in power supply	2 caps vented, 4 bulging, 3 meas bad. See Mouser order of x/x/xx for replacement parts.
x/x/xx	x	ipod docking alarm clock	ihome ih5	right selec-tor knob flakey		pop off knob, spray with contact cleaner
x/x/xx	x	tv	vizio sv470xv1a	no back-light	6632L-0487A backlight inverter slave	Unplugging bad slave board allowed 24v supply to come up on master board. Transistors on slave shorted.
x/x/xx	x	integrated amp	jvc ja-s55	phono preamp bad channel	x101 2sk240v/bl dual fet	adjust bias via r113
x/x/xx	x	jeep module	1994	bad caps	3-220µF 25v	jell encapsulated
x/x/xx	x	high resistance meter	keithley 6517a	overcur-rent error, v source stuck at –145v	Q314 [2N7000], Q313 [2SK1412] and Q317 [2SK1412]	The 2SK1412's didn't fail as pure open or short
x/x/xx	x	audio receiver	panasonic SA-BX500PP	dead	TDA8920BJ amp IC	originally suspect-ed power supply and replaced switch mode reg

CHAPTER 9

Product-Specific Repairs

This chapter provides specific repair advice for some of the most commonly repaired products, including flat-screen TVs, laptops, rechargeable battery packs, audio receivers, and remote controls.

The purpose of this chapter is not to cover every problem for every device but to give an idea of the scope of common repairs and provide guidance if no model-specific resources are available. Online resources such as iFixit.com have model-specific repair guides for thousands of devices and are a good place to start when considering any repair.

Flat-Screen TVs

Few products have changed as radically as televisions have over the years. And TV repair has changed with them. Back in the 1960s, tube testers were commonly found in drugstores, and do-it-yourselfers would bring in shoeboxes of vacuum tubes to check whenever their TVs acted up. In the subsequent decades, transistors and ICs replaced vacuum tubes, and televisions got more complex, pushing television repair beyond the capabilities of most do-it-yourselfers.

Now that televisions have almost a million times the computational power and memory of the Apollo 11 guidance computer, the tables have turned again. TV repair in the age of flat-screen TVs is now largely a matter of swapping broken modules. For those more adventurous, it may include replacing bad electrolytic capacitors in power supply boards. The skill is now in determining which module is bad.

What's Inside a Flat-Screen TV?

Figure 9-1 shows what's inside a typical flat-screen TV. The exact number of modules varies from model to model, but the configuration shown is very common. Table 9-1 lists and describes the typical modules and assemblies.

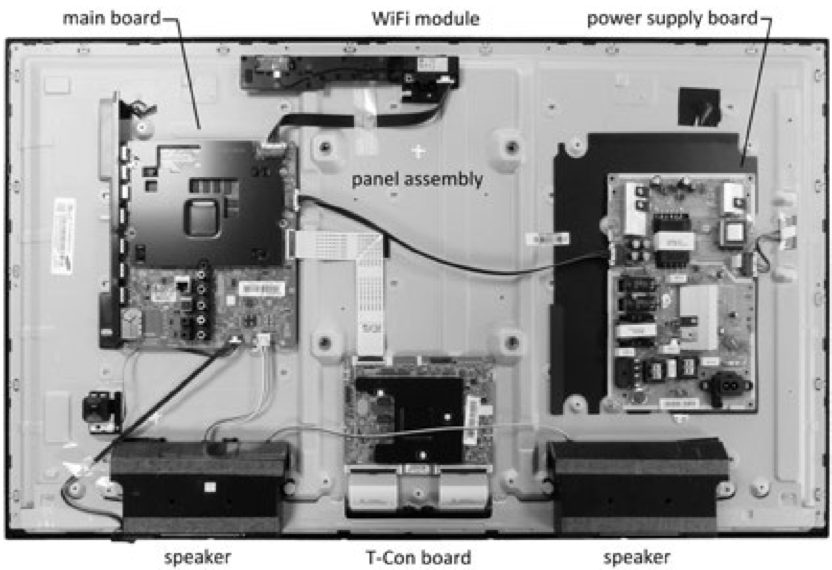

FIGURE 9-1 Inside a flat-screen TV.

Panel Assembly

Panel assemblies generally include a display panel layer as well as a backlight. Liquid-crystal display (LCD) panels do not in themselves emit light and require a backlight behind the LCD layer. In the past, cold-cathode fluorescent lamps (CCFL), miniature versions of fluorescent light tubes, were used for this, but current model LCD TVs use light-emitting diodes (LEDs) for backlighting. These are sometimes advertised as LED TVs, but they are in fact LCD TVs.

Another type of panel assembly, quantum-dot displays, also include an LCD layer but use a combination of blue LEDs and red and green quantum dots to produce a higher-quality backlight than ordinary LEDs.

A third type of panel assembly, organic LED (OLED) displays, emit light at the pixel level, and there is no LCD layer or backlight involved.

Power Supply Board

The power supply board converts the 120-VAC line voltage into the array of DC voltages needed by the other modules. It also provides the often high voltages needed to drive the backlight, which can be in the hundreds of volts for models with LED backlights and 500–700 volts for older LCD TVs with CCFL backlights.

Main Board

The main board performs audio and video processing. The television's microprocessor is also on the main board, generating all the user-interface graphics, responding to remote control commands, and providing smart TV functions.

T-Con Board

The timing controller (T-con) board converts the red-green-blue (RGB) video data and timing information from the main board into the control and data signals required for the row and column driving of the LCD.

TABLE 9-1 Recognizing Modules Inside a Flat-Screen TV

Module/Assembly	How to Recognize	What It Does
Panel assembly	—	Display panel and drive circuitry, includes backlight for LCD displays
Power supply board	AC power cord feeds this board	Provides DC power to other boards and to backlight
Main board	Has signal connectors (HDMI, USB, tuner input)	Performs audio and video processing; includes micro-processor
T-con board	Has three large, flexible flat cable connectors; may be integrated onto main board or panel assembly	Timing controller for the display panel
WiFi/Bluetooth module	Only a few square inches; may be integrated onto main board	Provides wireless internet and Bluetooth capabilities

Taking a Flat-Screen TV Apart

Before taking a TV apart, try a reset, and do a preliminary diagnosis as described in the next section. To disassemble and work on a flat-screen TV, use a flat, sturdy table that's at least as large as the screen. To protect the screen and bezel, cover the table with a blanket before laying the TV screen-side-down on the table. The TV should be unplugged during disassembly and repair.

Remove the TV stand or wall-mount bracket from the back of the TV. Next, remove all the screws holding the back of the TV on. In some cases, the entire back panel doesn't need to be removed; there's a smaller access panel that provides access to the internal modules. Use an egg carton to hold the screws. Use different colors or types of tape on the back of the TV (and the corresponding egg carton compartment) to indicate different screw types. Installing the wrong screw when you put the TV back together can damage internal circuitry if the screw is too long or can strip threads if it's too large in diameter.

Once all the screws are out, gently lift the back off. If there's a spot that doesn't seem to want to lift off, you may have missed a screw. Sometimes there are wires connecting power switches or other assemblies attached to the cabinet back to the main board in the TV, so separate the back from the TV slowly to prevent breaking a wire or connector.

SAMSUNG OPEN JIG

In rare instances, TV manufacturers choose to require special tools for disassembly. For Samsung screwless-back TVs, the tool you'll need is shown in Figure 9-2. There are plenty of online videos demonstrating how to use it.

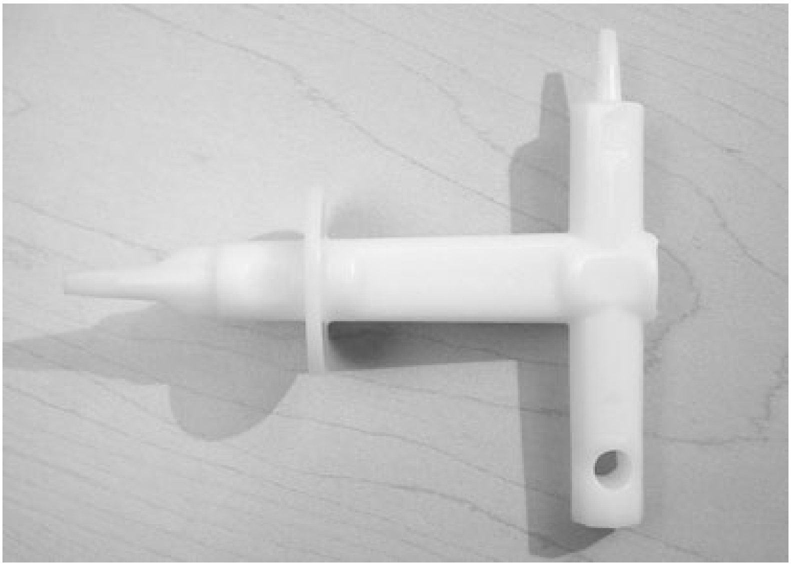

FIGURE 9-2 Samsung Open Jig.

To remove modules for repair or replacement, you'll need to carefully disconnect all cables to that module (Fig. 9-3). Use your phone to take pictures before disconnecting cables if there's any chance of reassembly error. The "Board Connectors" section in Chapter 8 shows the most commonly used connectors in TVs and how to take them apart without damage.

Finding Replacement Laptop Parts

When shopping for replacement screens or other laptop parts, search by the model number of the laptop as well as by the many numbers found on the part itself. Some part sellers may use one number for the part, and others may use a different number. Searching different ways will give you the best price and availability. If you don't care whether your screen is glossy or matte, you'll have even more options available.

Be sure that the connectors on replacement screens and keyboards are identical in type and location to those on the original. The same model laptop may have multiple versions using different connectors.

Laptop Cracked Screen Replacement

The following procedure is for a representative laptop and will differ significantly by manufacturer and model. Laptops with large bezels around the screen are usually the easiest on which to replace screens. Refer to Figure 9-4.

1. Turn off the laptop, and unplug the AC adapter. Remove the battery if easily accessible.
2. Remove the plastic bezel by gently popping it off at the top and working your way around the perimeter of the screen.
3. Remove the screws holding the screen to the top cover, as shown in photo b of the figure. Cover the keyboard with a paper towel, and lay the screen onto the keyboard (photo c).
4. The 30-pin connector uses clear tape to keep it from separating. Peel back the tape enough to allow separation, and separate the wiring harness from the screen (photos d and e).
5. Replace the damaged screen with the new one, and reverse the disassembly steps to reassemble the laptop. Be sure that the wiring bundle is pushed into its retainers (photo f).
6. Test the new panel before reinstalling the bezel. If it works properly, reinstall the bezel.

FIGURE 9-4 Laptop cracked screen replacement.

FIGURE 9-7 Sub C batteries with solder tabs.

Rebuilding a Battery Pack

Follow these steps and refer to Figure 9-8 to rebuild a battery pack:

1. Disassemble the battery cartridge or device to reveal the batteries (photo b of the figure). Determine their chemistry, capacity, and physical dimensions. Order cells as needed.
2. Arrange the cells in the same way as the originals, aligning the positive solder tab of one cell with the negative solder tab of the next cell. Use tape or hot glue to maintain alignment (photo c).
3. Solder the mating solder tabs together, and solder the battery connection wires to the outermost solder tabs (photos d and e).
4. Reassemble the cartridge or device by reversing the disassembly steps.

FIGURE 9-9 NiCd cells with taped ends.

Audio Receivers and Power Amps

The two most common problems with audio receivers and power amps are bad electrical contacts or blown output amplifier circuitry.

Electrical Contact Problems

Bad electrical contacts can be in selector switches, input and output jacks, and controls such as volume and balance. Contact problems are often intermittent and are common in vintage audio gear. Electrical contacts oxidize over time from exposure to the air, resulting in intermittent or bad connections. In mild cases, this produces scratchy volume and tone controls. In more extreme cases, equipment just does not work.

WHY IS BIAS ADJUSTMENT NEEDED?

Figure 9-10 shows a Class AB complementary amplifier output stage. *Complementary* means that matching NPN and PNP transistors are used to source and sink current at the speaker output. The output stage is driven by preamp and bias circuitry.

Music produces both positive and negative output swings. For positive swings, transistor Q3 provides the positive current to the speaker output. For negative swings, transistor Q4 provides the negative current to the speaker output. As the output approaches zero, there's a handoff between the two transistors. The bias current determines the overlap in the operation of the two transistors to provide a smooth handoff.

If the bias current is too low, one transistor turns off before the other turns on, producing audible distortion at the switching point. If the bias current is too high, the output transistors will run hotter than necessary. This wastes power and reduces their reliability. Adjusting the bias current is a compromise between these two extremes.

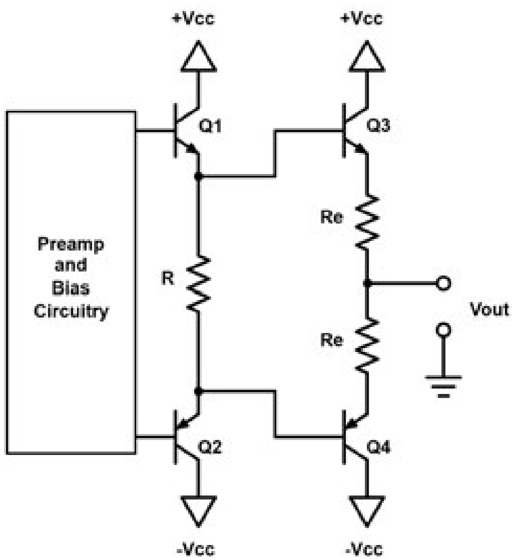

FIGURE 9-10 BJT amplifier complementary output stage.

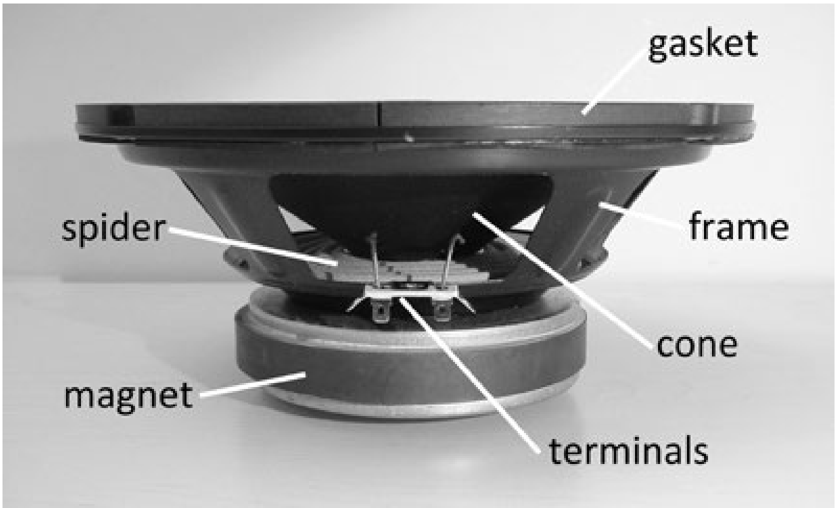

FIGURE 9-14 Woofer anatomy, side view.

Surrounds can be made of rubber, foam, or other materials. Surrounds made of foam eventually deteriorate and develop tears or holes. Once this happens, the woofer is at high risk of mechanical damage because the damaged foam can't keep the cone properly aligned, and the voice coil assembly at the base of the cone can begin to rub, causing voice coil damage.

Fortunately, it's possible to replace the foam surround on any woofer, but it's important to check beforehand whether the woofer is otherwise okay. If the foam has just started to develop minor tears or holes, the outlook is good. Play music through the speaker in its cabinet and listen for distortion or rubbing. Compare it against its companion speaker if you're having trouble deciding if there's a problem. If the surround is so badly deteriorated that you can wiggle the cone from side to side, there may be voice coil damage.

To Shim or Not to Shim

The basic idea behind replacing a woofer surround is simple: remove the old surround, and glue in a fresh one. The tricky part is making sure that the new surround is glued in so that the cone is perfectly centered. If it isn't, the voice coil will rub, and you'll have to redo the whole procedure. There are two techniques for replacing surrounds, shims, or shimless (Table 9-4).

TABLE 9-4 Advantages and Disadvantages of Shimming

Technique	Advantage	Disadvantage
Shims	Very low risk of having to redo	Must replace dust cap
Shimless	Fewer steps can be used with all woofers.	Requires more finesse, with a higher risk of having to redo.

Shims and voice coil rub can be understood by looking at Figure 9-15. Diagram a shows the parts of a woofer, including the voice coil and pole piece. These are the parts that can rub together if the cone isn't

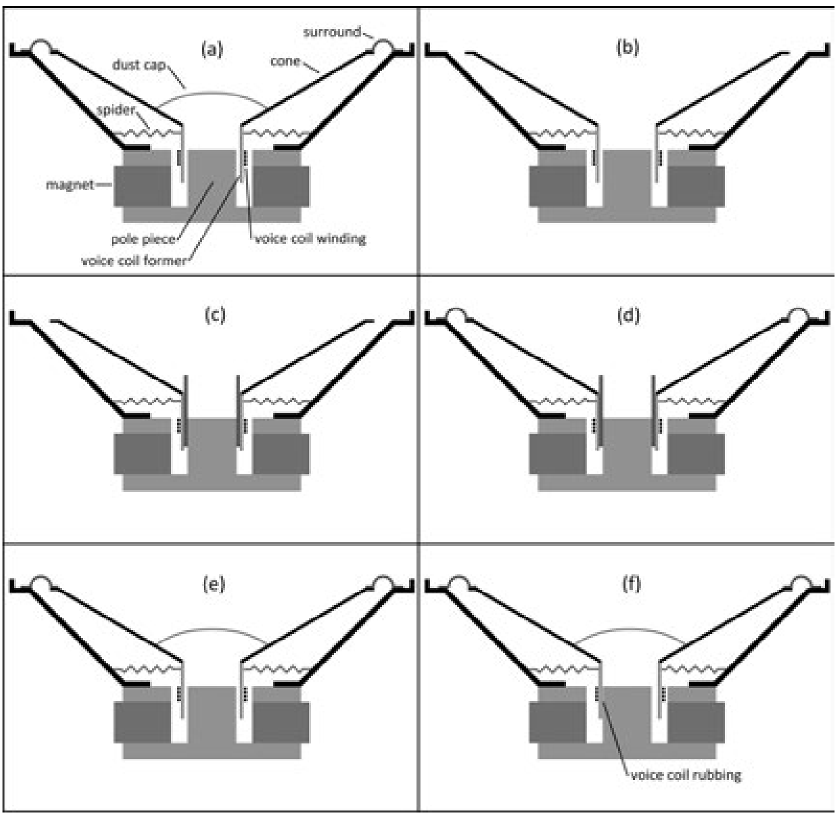

FIGURE 9-15 Using shims during repair to avoid voice coil rub.

Battery Problems

If the remote seems dead, remove the batteries and inspect the contacts in the remote. If there are any signs of corrosion, use the eraser on the top of a pencil to scrub them. If there's battery leakage, clean the contacts with damp cotton swabs and a dental pick. Put in fresh batteries, making sure that they're installed correctly. Usually, the springs go to the negative battery terminals, but not always. Trust the plus and minus signs not whether there's a spring.

If this doesn't fix the problem, use the camera test for remote controls described in the sidebar to determine whether the remote is sending out infrared commands or not.

CAMERA TEST FOR REMOTE CONTROLS

Infrared (IR) remote controls send out IR light pulses to control their companion devices. The human eye can't see IR light, but many digital cameras found in phones, tablets, and laptops can (Fig. 9-21).

FIGURE 9-21 Camera test for remote controls.

In a dark setting, point the remote control toward the camera, and press the volume-up button. (Volume-up keeps sending pulses as long as you press the button.) If the remote is working and your camera is sensitive to IR light, you'll see a glow from the IR LED in the remote. If you don't see a glow, try another camera device or

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