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Chapter 26

Troubleshooting and Maintenance

The robust and self-reliant ethic of amateur radio is nowhere stronger than in the amateur's ability to maintain, troubleshoot, and repair electronic equipment. Amateurs work with not just radios, but all sorts of equipment from computers and software to antennas and transmission lines. This flexibility and resilience are keys to fulfilling the FCC Part 97.1 Basis and Purpose of amateur radio.

The sections on troubleshooting approaches, tools and techniques build on earlier material written by Ed Hare, W1RFI. They will help you approach troubleshooting in an organized and effective manner, appropriate to your level of technical experience and tools at hand. This material shows how to get started and ask the right questions — often the most important part of troubleshooting.

Additional sections on troubleshooting power supplies, amplifiers, radios and antenna systems and tuners (contributed or updated by Matt Kastigar, WØMJ; Tom Schiller, N6BT; Ted Thrift, VK2ARA; and Ross Pittard, VK3CE) tackle the most common troubleshooting needs. Restoring and maintaining vintage equipment is a popular part of ham radio, and so there are some sections by John Fitzsimmons, W3JN, and Pat Bunsold, WA6MHZ, on the special needs of this equipment.

This chapter is organized in three groups of sections to be consulted as required for any particular troubleshooting need. You will not need to read it from end-to-end in order to troubleshoot successfully. The first group of sections covers test equipment details, pertinent information about components, and safety practices. The second group presents general guidelines and techniques for effective troubleshooting. The third group presents specific advice and information on equipment that is commonly repaired by amateurs.

TROUBLESHOOTING — ART OR SCIENCE?

Although some say troubleshooting is as much art as it is science, the repair of electronic gear is not magic. It is more like detective work. Knowledge of advanced math or electronics theory is not required. However, you must have, or develop, a good grasp of basic electronics and simple measurements, guided by the ability to read a schematic diagram and to visualize signal flow through the circuit. As with most skills, these abilities will develop with practice.

Not everyone is an electronics wizard; your gear may end up at the repair shop in spite of your best efforts. The theory you learned for the FCC examinations and the information in this *Handbook* can help you decide if you can fix it yourself. Even if the problem appears to be complex, most problems have simple causes. Why not give troubleshooting a try to the best of your abilities? Maybe you can avoid the effort and expense of shipping the radio to the manufacturer. It is gratifying to save time and money, but the experience and confidence you gain by fixing it yourself may prove even more valuable.

SAFETY FIRST! — SWITCH TO SAFETY

Always! Death is permanent. A review of safety must be the first thing discussed in a troubleshooting chapter. Some of the voltages found in amateur equipment can be fatal! Only 50 mA flowing through the body is painful; 100 to 500 mA is usually fatal. Under certain conditions, as little as 24 V can kill. RF exposure in a high-power amplifier can create severe burns very quickly. Batteries can deliver huge amounts of power that can melt tools and wires or create an explosion when short-circuited. Charging lead-acid cells can create a buildup of explosive hydrogen gas.

Make sure you are 100% familiar with all safety rules and the dangerous conditions that might exist in the equipment you are servicing. A list of safety rules can be found in **Table 26.1**. You should also read the **Safety** chapter of this *Handbook* — all of it — before you begin to work on equipment.

Remember, if the equipment is not working properly, dangerous conditions may exist where you don't expect them. Treat every component as potentially "live." Some older equipment uses "ac/dc" circuitry. In this circuit, one side of the chassis is connected directly to the ac line, a condition unexpected by today's amateurs, who are accustomed to modern safety standards and practices. This is an electric shock waiting to happen.

The maximum voltage rating of voltmeters and oscilloscopes is not often noted by the hobbyist, but it is crucial to safety when working on voltages higher than the household ac line voltage. Test equipment designed to measure voltage always has a maximum safe voltage rating between the circuit being measured and the equipment user — you! This is particularly

Table 26.1
Safety Rules

1. Keep one hand in your pocket when working on live circuits or checking to see that capacitors are discharged.
2. Include a conveniently located ground-fault current interrupter (GFCI) circuit breaker in the workbench wiring.
3. Use only grounded plugs and receptacles.
4. Use a GFCI protected circuit when working outdoors, on a concrete or dirt floor, in wet areas, or near fixtures or appliances connected to water lines, or within six feet of any exposed grounded building feature.
5. Use a fused, power limiting isolation transformer when working on ac/dc devices.
6. Switch off the power, disconnect equipment from the power source, ground the output of the internal dc power supply, and discharge capacitors when making circuit changes.
7. Do not subject electrolytic capacitors to excessive voltage, ac voltage or reverse voltage.
8. Test leads should be well insulated and without cracks, fraying, or exposed conductors.
9. Do not work alone!
10. Wear safety glasses for protection against sparks and metal or solder fragments.
11. Be careful with tools that may cause short circuits.
12. Replace fuses only with those having proper ratings.
13. Never use test equipment to measure voltages above its maximum rating.

important in handheld equipment in which there is no metal enclosure connected to an ac safety ground. Excessive voltage can result in a flashover to the user from the internal electronics, probes, or test leads, resulting in electric shock. Know and respect this rating.

If you are using an external high voltage probe, make sure it is in good condition with no cracks in the body. The test lead insulation should be in good condition — flexible and with no cracks or wire exposed. If practical, do not make measurements while holding the probe or meter. Attach the probe with the voltage discharged and then turn the power on. Turn power off and discharge the voltage before touching the probe again. Treat high voltage equipment with care and respect!

Soldering Safety

Remember that soldering tools and melted solder can be hot and dangerous! Wear protective goggles and clothing when soldering. A full course in first aid is beyond the scope of this chapter, but if you burn your skin, run the burn immediately under cold water and seek first aid or medical attention. Always seek medical attention if you burn your eyes; even a small burn can develop into serious trouble.

UNDERSTANDING THE BASICS

To fix electronic equipment, you need to understand the system and circuits you are troubleshooting. A working knowledge of electronic theory, circuitry and components is an important part of the process. When you are troubleshooting, you are looking for specific conditions that cause the symptoms you are experiencing. Knowing how circuits are supposed to work will help you to notice things that are out of place or that indicate a problem.

To be an effective troubleshooter, review and understand the following topics discussed elsewhere in this book:

- Ohms law and basic resistor circuits (**Electrical Fundamentals**)
- Basic transistor and diode characteristics (**Circuits and Components**)
- Fundamental digital logic and logic signals (**Digital Basics** supplement)
- Voltage and current measurements (**Test Equipment and Measurements**)
- SWR and RF power measurement (**Transmission Lines**)

You would be surprised at how many problems — even problems that appear complicated — turn out to have a simple root cause found by understanding the fundamentals and methods of one of these categories.

GETTING HELP

Other hams may be able to help you with your troubleshooting and repair problems, either with a manual or technical help. Check with your local club or repeater group. You may get lucky and find a troubleshooting wizard. (On the other hand, you may get some advice that is downright dangerous, so be selective.) Most clubs have one or two troubleshooting gurus who can provide guidance and advice, if not some on-the-workbench help.

There is a wealth of information available online, too. Many of the popular brands of equipment and even specific models have their own online communities or user's groups. The archives of these groups — almost universally free to join — contain much valuable troubleshooting, modification and operating information. If the problem doesn't appear to have been described, you can ask the group.

The Technology area of the ARRL's website also has an extensive section on Servicing Equipment (**www.arrl.org/servicing-equipment**). That page features articles and other resources, including links to schematic databases.

Your fellow hams in the ARRL Field organization may also help. Technical Coordinators (TC) and Technical Specialists (TS) are volunteers who are willing to help hams with technical questions. For the name and address of a local TC or TS, contact your Section Manager (listed in the front of any recent issue of *QST*).

Using Search Engines for Troubleshooting

The power of Internet search engines can save huge amounts of time when troubleshooting equipment. The key is in knowing how to construct the right list of words for them to find. Precision is your friend — be exact and use words others are likely to use if they had the same problem. Use the primary model number without suffixes to avoid being too specific. For example, when troubleshooting the well-known PLL potting compound problem exhibited by Kenwood TS-440 transceivers, entering the search string "TS-440 display dots" immediately finds many web pages dealing with the problem, while simply entering "Kenwood transceiver blank display" returns dozen of unrelated links.

Start with a very specific description of the problem and gradually use less exact terms if you don't find what you want. Learn how to use the "Advanced Search" functions of the search engine, too.

26.1 Test Equipment

Many of the steps involved in effiicient troubleshooting require the use of test equipment. We cannot see electricity directly, but we can measure its characteristics and effects. Our test equipment becomes our electrical senses.

The **Test Equipment and Measurements** chapter is where you can find out more about various common types of equipment, how to operate it, and even how to build some of your own. There are many articles in *QST* and in books and websites that explain test equipment and offer build-it-yourself projects, too. Surplus equipment of excellent quality is widely available at a fraction of its new cost.

You need not purchase or build every type of test equipment. Specialty equipment such as spectrum analyzers or UHF frequency counters can often be borrowed from a club member or friend — maybe one of those troubleshooting gurus mentioned earlier. If you own the basic instruments and know how to use them, you'll be able to do quite a bit of troubleshooting before you need the special instruments.

26.1.1 Senses

Although they are not test equipment in the classic sense, your own senses will tell you as much about the equipment you are trying to fix as the most-expensive spectrum analyzer. We each have some of these natural test instruments.

Eyes — Use them constantly. Look for evidence of heat and arcing, burned components, broken connections or wires, poor solder joints or other obvious visual problems.

Ears — Severe audio distortion can be detected by ear. The snaps and pops of arcing or the sizzling of a burning component may help you track down circuit faults. An experienced troubleshooter can diagnose some circuit problems by the sound they make. For example, a bad audio-output IC sounds slightly different from a defective speaker.

Nose — Your nose can tell you a lot. With experience, the smells of ozone, an overheating transformer, and a burned resistor or PC board trace each become unique and distinctive. Many troubleshooting sessions begin with "something smells hot!"

Finger — After using a voltmeter to ensure no hazardous voltages are present, you can use a fingertip to determine low heat levels— never do this in a high-voltage circuit. Use a temperature probe if using a finger is unsafe. Small-signal transistors can be fairly warm, but being very hot indicates a circuit problem. Warm or hot capacitors are always suspect. High-power devices and resistors can be quite hot during normal operation.

Brain — More troubleshooting problems have been solved with a multimeter and a brain than with the most expensive spectrum analyzer. You must use your brain to analyze data collected by other instruments.

26.1.2 Internal Equipment

Some test equipment is included in the equipment you repair. Nearly all receivers include a speaker. An S meter is usually connected ahead of the audio chain. If the S meter shows signals, that indicates that the RF and IF circuitry is probably functioning. Transmitters often have a power supply voltage and current meter, along with power output, SWR, ALC and speech compression readings that give valuable clues about what is happening inside the equipment.

The equipment also has visual indicator lights that provide additional information such as transmit status, high SWR, low voltage, squelch status, and so forth. These readings or indicators are often specifically referenced by the troubleshooting sections of manuals to help sort out problems.

Microprocessor-controlled equipment often provides error indications, either through a display or by indicator lights. In addition, faults detected by the control software are sometimes communicated through patterns of beeps or flashing of LEDs. Each sequence has a specific meaning that is described in the operating or service manual.

26.1.3 Bench Equipment

The following is a list of the most common and useful test instruments for troubleshooting. Some items serve several purposes and may substitute for others on the list. The theory and operation of most of this equipment is discussed in detail in the **Test Equipment and Measurements** chapter. Notes about the equipment's use for troubleshooting are listed here.

Multimeters —The most often used piece of test equipment, the digital multimeter or DMM, can often test capacitors of most values in addition to voltage, current and resistance. Most can test diodes and transistors on a go/no-go basis, while some can measure gain. Some can even measure frequency or use an external probe to measure temperature.

Some DMMs are affected by RF, so most technicians keep an old-style analog moving-needle VOM (volt-ohm-meter) on hand for use in strong RF fields. Some technicians prefer the moving needle for peaking or nulling adjustments.

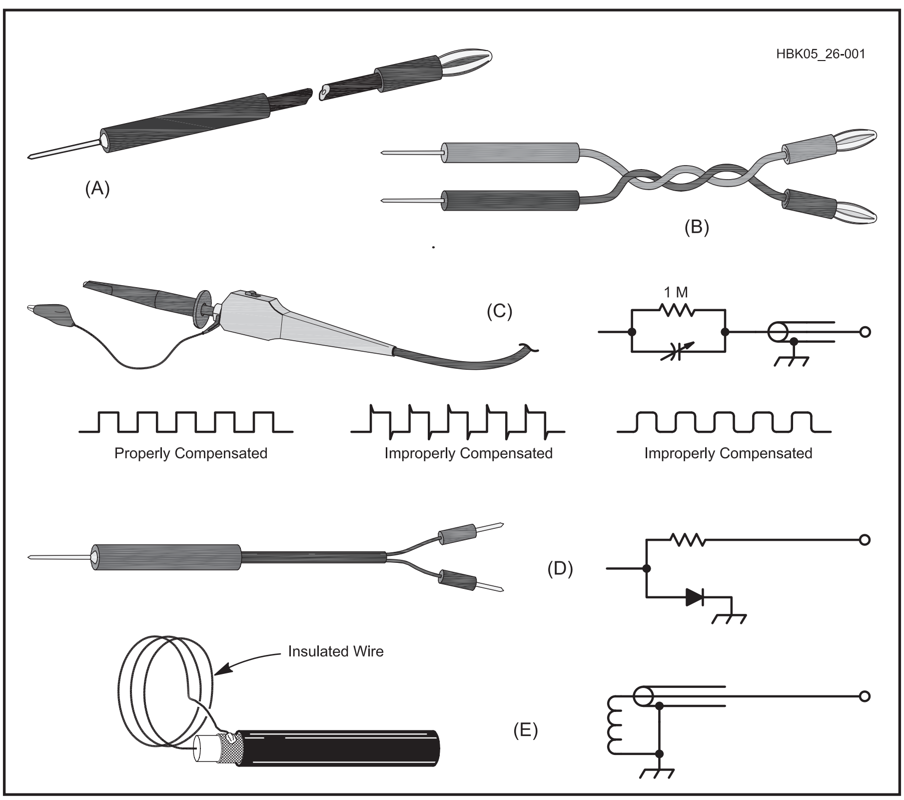

Figure 26.1 — An array of test probes for use with various test instruments.

Figure 26.2 — A clamp-on meter probe is used with a digital multimeter for measuring ac current (left). Meters are also available integrated with the clamp-on probe (right).

Test or clip leads — Keep an assortment of these wires with insulated alligator clips. Commercially made leads have a high failure rate because they use small wire that is not soldered to the clips, just crimped. You can slip off the clip jackets and solder the wire yourself for better reliability. Making a set of heavier-gauge leads is a good idea for currents above several hundred milliamps.

Individual wire leads (**Figure 26.1A**) are good for dc measurements, but they can pick up unwanted RF energy. This problem is reduced somewhat if the leads are twisted together (Figure 26.1B). Coaxial cable test leads can avoid RF pickup but also place a small capacitance across the circuit being measured. The added capacitance may affect performance.

Test probes — The most common probe is the low-capacitance (×10) oscilloscope probe shown in Figure 26.1C. This probe isolates the oscilloscope from the circuit under test, preventing the scope's input and test-probe capacitance from affecting the circuit and changing the reading. A network in the probe serves as a 10:1 divider and compensates for frequency distortion in the cable and test instrument.

Demodulator probes (see the **Test Equipment and Measurements** chapter and the schematic shown in Figure 26.1D) are used to demodulate or detect RF signals, converting modulated RF signals to audio that can be heard in a signal tracer or seen on a low-bandwidth scope.

You can make a probe for inductive coupling as shown in Figure 26.1E. Connect a two or three-turn loop across the center conductor and shield before sealing the end. The inductive pickup is useful for coupling to high-current points and can also be used as a sniffer probe to pick up RF signals without contacting a circuit directly.

Other common types of probes are the non-contact clamp-on probes shown in **Figure 26.2** that use magnetic fields to measure current. A high-voltage probe for use with DMMs or VOMs is shown in **Figure 26.3** and is discussed more in this chapter's section on power supply troubleshooting.

Thermocouple and active temperature sensor probes are also commonly available. These display temperature directly on the meter in °F or °C.

RF power and SWR meters — Simple meters indicate relative power SWR and are fine for adjusting matching networks and monitoring transmission line conditions for problems. However, if you want to make accurate measurements, a calibrated directional RF wattmeter with the proper sensing elements for the frequencies of signals being measured is required.

Dummy load — Do not put a signal on the air while repairing equipment. Defective equipment can generate signals that interfere with other hams or other radio services. A dummy load also provides a known, matched load (usually 50 Ω) for use during adjustments and test measurements. See the **Transmitting** chapter.

Dip meter — As described in the **Test Equipment and Measurements** chapter, dip meters are used to adjust and troubleshoot resonant circuits. Many can perform as an absorption frequency meter, as well. Dip meters can be used as low-power signal sources but are not very stable.

New dip meters are fairly rare. When purchasing a dip meter, look for one that is mechanically and electrically stable. All of the coils should be present and in good condition. A headphone connection is helpful. Battery operated models are easier to use for antenna measurements. Dip meters are not nearly as common as they once were.

Oscilloscope — The oscilloscope, or scope, is the second most often used piece of test equipment, although a lot of repairs can be accomplished without one. The trace of a scope can give us a lot of information about a signal at a glance. For example, when signals from the input and output of a stage are displayed on a dual-trace scope, stage linearity and phase shift can be checked (see **Figure 26.4**).

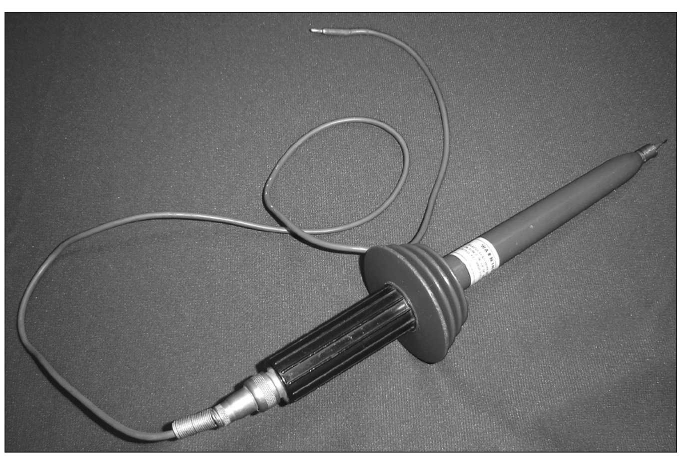

Figure 26.3 — A probe used for measuring high-voltage with a standard multimeter.

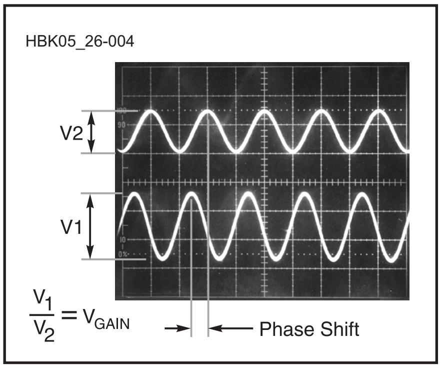

Figure 26.4 — A dual-trace oscilloscope display of amplifier input and output waveforms.

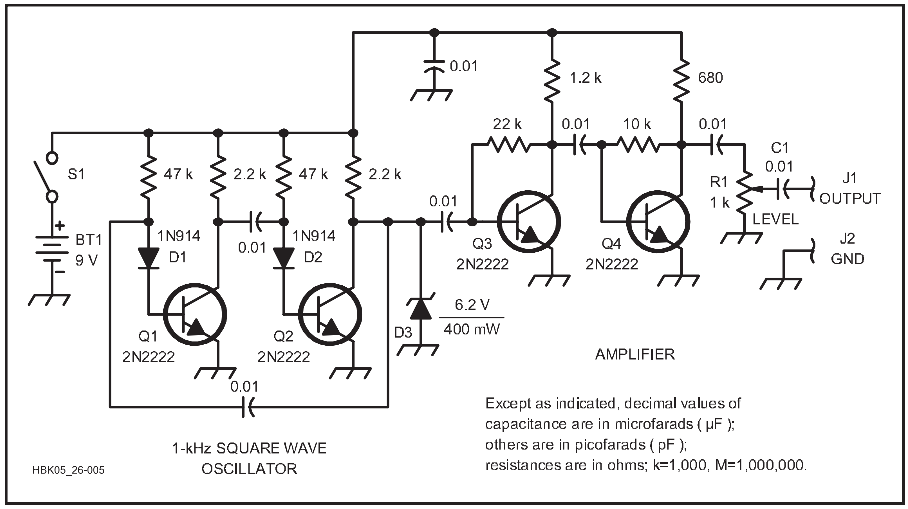

Figure 26.5 — Schematic of the AF/RF signal injector. All resistors are ¼ W, 5% carbon units, and all capacitors are disc ceramic. A full-size etching pattern and parts-placement diagram can be found in the downloadable supplemental content.

BT1 — 9 V battery.
D1, D2 — Silicon switching diode, 1N914 or equiv.
D3 — 6.2 V, 400 mW Zener diode.
J1, J2 — Banana jack.
Q1-Q4 — General-purpose silicon NPN transistors, 2N2222 or similar.
R1 — 1 kΩ panel-mount control.
S1 — SPST toggle switch.

An oscilloscope will show gross distortions of audio and RF waveforms, but it cannot be used to verify that a transmitter meets FCC regulations for harmonics and spurious emissions. Harmonics that are down only 20 dB from the fundamental would be illegal in most cases, but they would not change the oscilloscope waveform enough to be seen.

When buying a scope, get the highest bandwidth you can afford. Old Hewlett-Packard or Tektronix instruments are usually quite good for amateur use.

Signal generator — Although signal generators have many uses, in troubleshooting they are most often used for signal injection (more about this later) and alignment of vintage equipment.

When buying a generator, look for one that can generate a sine wave signal. A good signal generator is double or triple shielded against leakage. Fixed-frequency audio should be available for modulation of the RF signal and for injection into audio stages. The most versatile generators can generate amplitude and frequency modulated signals. Used Hewlett-Packard (Agilent) and Tektronix units are typically available for reasonable prices but may not be repairable if they fail due to unavailable parts.

Good generators have stable frequency controls with no backlash. They also have multiposition switches to control signal level. A switch marked in dBm is a good indication that you have located a high-quality test instrument. The output jack should be a coaxial connector (usually a BNC or N), not the kind used for microphone connections.

In lieu of a fully tunable generator, you can build some simple equipment that generates a signal. For example, Elecraft makes the XG3 kit — a programmable signal source (**www.elecraft.com**) that generates 160 through 2 meter signals with 4 calibrated output levels. It's very useful for receiver calibration, sensitivity tests and signal tracing.

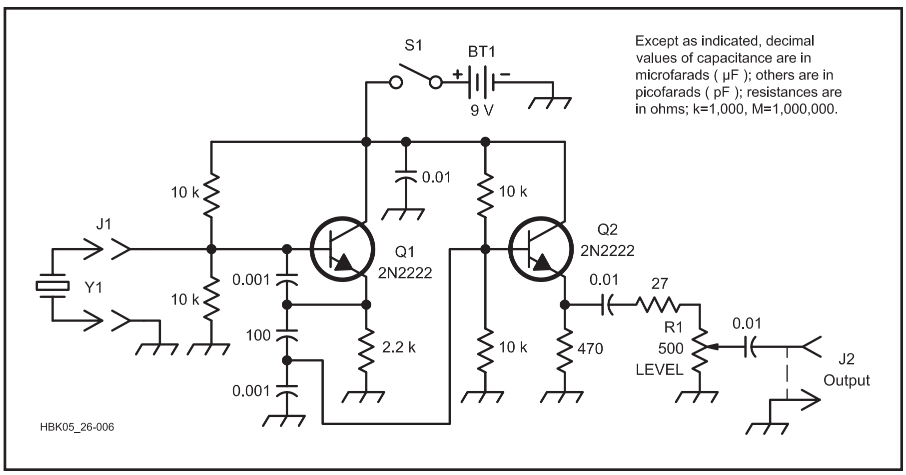

Figure 26.6 — Schematic of the crystal-controlled signal source. All resistors are ¼ W, 5% carbon units, and all capacitors are disc ceramic. A full-size etching pattern and parts-placement diagram can be found in the downloadable supplemental content.

BT1 — 9 V transistor radio battery.
J1 — Crystal socket to match the crystal type used.
J2 — RCA phono jack or equivalent.
Q1, Q2 — General-purpose silicon NPN transistors, 2N2222 or similar.
R1 — 500 Ω panel-mount control.
S1 — SPST toggle switch.
Y1 — 1 to 15-MHz crystal.

Even simpler, you can homebrew the AF/RF signal-injector schematic as shown in **Figure 26.5**. If frequency accuracy is needed, the crystal-controlled signal source of **Figure 26.6** can be used. The AF/RF circuit provides usable harmonics up to 30 MHz, while the crystal controlled oscillator will function with crystals from 1 to 15 MHz. These two projects are not meant to replace standard signal generators for alignment and precision testing, but they are adequate for generating signals that can be used for general troubleshooting. (See the section on Signal Tracing and Signal Injection.)

Signal tracer — Signals can be traced with a voltmeter and an RF probe, a dip meter with headphones or an oscilloscope, but signal tracers combine these functions especially for signal tracing through a receiver or other RF signal processing circuit. Articles describing the use of signal tracers, including a project you can build yourself, are provided with the downloadable supplemental content.

A general-coverage receiver can be also used to trace RF or IF signals, if the receiver covers the necessary frequency range. Most receivers, however, have a low-impedance input that severely loads the test circuit. To minimize loading, use a capacitive probe or loop pickup as in Figure 26.1. When the probe is held near the circuit, signals will be picked up and carried to the receiver. It may also pick up stray RF, so make sure you are listening to the correct signal by switching the circuit under test on and off while listening.

Transistor tester — Most transistor failures appear as either an open or shorted junction. Opens and shorts can be found easily with an ohmmeter or the diode junction checker of a standard DMM; a special tester is not required.

Transistor testers measure device current while the device is conducting or while an ac signal is applied at the control terminal. Transistor gain characteristics vary widely even between units with the same device number. Testers can be used to measure the gain of a transistor. DMM testers measure only transistor dc alpha and beta. Testers that apply an ac signal show the ac alpha or beta. Better testers also test for leakage.

In addition to telling you whether a transistor is good or bad, a transistor tester can help you decide if a particular transistor has sufficient gain for use as a replacement. It may also help when matched transistors are required. The final test is the repaired circuit.

Frequency counter — Most inexpensive frequency counters display frequency with 1 Hz resolution or better up to around low VHF frequencies. Some may include a prescaler that divides higher frequencies by 10 to extend the counter's range. Good quality used counters are widely available.

Power supplies — A well-equipped test bench should include a means of varying the ac-line voltage, a variable-voltage regulated dc supply and an isolation transformer.

AC-line voltage varies slightly with load. An autotransformer with a movable tap (also known by the trade name Variac) lets you boost or reduce the line voltage slightly. This is helpful to test circuit functions with supply-voltage variations.

An isolation transformer is required to work safely on vintage equipment, which often ties one side of the ac line to the chassis. An isolation transformer is also required when working on any equipment or circuits that operate directly connected to the line. Note that your test equipment will also have to be powered through the isolation transformer in such cases!

A good multi-voltage supply will help with nearly any analog or digital troubleshooting project. Many electronics distributors stock bench power supplies. A variable-voltage dc supply may be used to power various small items under repair or provide a variable bias supply for testing active devices. Construction details for a laboratory power supply appear in the **Power Sources** chapter.

Heat and cold sources **—** Many circuit problems are sensitive to temperature. A piece of equipment may work well when first turned on (cold) but fail as it warms up. In this case, a cold source will help you find the intermittent connection. When you cool the bad component, the circuit will suddenly start working again (or stop working). Cooling sprays are available from most parts suppliers.

A heat source helps locate components that fail only when hot. A small incandescent lamp can be mounted in a large piece of sleeve insulation to produce localized heat for test purposes. The tip of a soldering iron set to low heat can also be used.

A heat source is usually used in conjunction with a cold source. If you have a circuit that stops working when it warms up, heat the circuit until it fails, then cool the components one by one. When the circuit starts working again, the last component sprayed was the bad one.

Stethoscope — A stethoscope (with the pickup removed — see **Figure 26.7**) or a long piece of sleeve insulation can be used to listen for arcing or sizzling in a circuit. Remove any metal parts at the end of the pickup tube before use for troubleshooting live equipment.

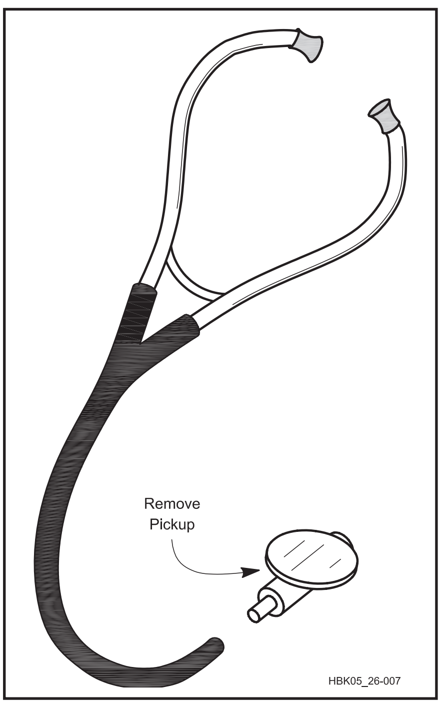

Figure 26.7 — A stethoscope, with the pickup and all metal hardware removed from the listening tube, is used to listen for arcing in crowded circuits.

The Shack Notebook

A shack notebook is an excellent way to keep track of test results, wiring, assembly notes, and so forth. If you haven't already started one, now is a good time. All it takes is an inexpensive composition book or spiral-bound notebook. The books filled with graph paper are especially good for drawing and making graphs.

The goal is to have one place where information is collected about how equipment was built, performs, or operates. The notebook is invaluable when trying to determine if performance has changed over time, or what color code was used for a control cable, for example.

Before beginning a test session or when adding a new piece of equipment to your shack, get out the shack notebook first and have it available as you work. For new equipment, record serial numbers, when installed, whether it was modified or specially configured to work in your station, etc. For a new antenna or feed line, it's a good idea to make a few SWR measurements so you can refer to them later if something seems wrong in the antenna system. Be sure to include the date of any entries as well.

You can also make good use of that digital camera, even the one in your mobile phone. Take pictures of equipment, inside and out, to document how it is assembled or configured. This can be very helpful when you have to maintain the equipment later.

26.2 Components

Once you locate a defective part, it is time to select a replacement. This is not always an easy task. Each electronic component has a function. This section acquaints you with the functions, failure modes and test procedures of resistors, capacitors, inductors and other components. Test the components implicated by symptoms and stage-level testing. In most cases, a particular faulty component will be located by these tests. If a faulty component is not indicated, check the circuit adjustments. As a last resort, use a "shotgun" approach — replace all parts in the problem area with components that are known to be good.

26.2.1 Check the Circuit

Before you install a replacement component of any type, you should be sure that another circuit defect didn't cause the failure. Check the circuit voltages carefully before installing any new component, especially on each trace or connection to the bad component. The old part may have died as a result of a lethal voltage. Measure twice — repair once! (With apologies to the old carpenter...) Of course, circuit performance is the final test of any substitution.

26.2.2 Fuses

Most of the time, when a fuse fails, it is for a reason — usually a short circuit in the load. A fuse that has failed because of a short circuit usually shows the evidence of high current: a blackened interior with little blobs of fuse element everywhere. Fuses can also fail by fracturing the element at either end. This kind of failure is not visible by looking at the fuse. Check even fuses thought to be good with an ohmmeter. You may save hours of troubleshooting.

For safety reasons, always use *exact* replacement fuses. Check the current and voltage ratings. The fuse timing (fast, normal or slow blow) must be the same as the original. Never attempt to force a fuse that is not the right size into a fuse holder. The substitution of a bar, wire or penny for a fuse invites a smoke party.

26.2.3 Wires and Cables

Wires seldom fail unless abused. Short circuits can be caused by physical damage to insulation or by conductive contamination. Damaged insulation is usually apparent during a close visual inspection of the conductor or connector. Look carefully where conductors come close to corners or sharp objects. Repair worn insulation by replacing the wire or securing an insulating sleeve (spaghetti) or heat-shrink tubing over the worn area.

When wires fail, the failure is usually caused by stress and flexing. Nearly everyone has broken a wire by bending it back and forth, and broken wires are usually easy to detect. Look for sharp bends or bulges in the insulation.

When replacing conductors, use the same material and size, if possible. Substitute only wire of greater cross-sectional area (smaller gauge number) or material of greater conductivity. Insulated wire should be rated at the same, or higher, temperature and voltage as the wire it replaces.

Cables used for audio, control signals, and feed lines sometimes fail from excessive flexing, being crimped or bent too abruptly, or getting pulled out of connectors. As with replacing wires, use the same cable type or one with higher ratings.

26.2.4 Connectors

Connection faults are one of the most common failures in electronic equipment. This can range from something as simple as the ac-line cord coming out of the wall, to a connector having been inserted into the wrong socket, to a defective IC socket. Connectors that are plugged and unplugged frequently can wear out, becoming intermittent or noisy. Inspect male connectors for bent pins, particularly miniature connectors with very small pins. Check connectors carefully when troubleshooting.

Connector failure can be hard to detect. Most connectors maintain contact as a result of spring tension that forces two conductors together. As the parts age, they become brittle and lose tension. Any connection may deteriorate because of nonconductive corrosion at the contacts. Solder helps prevent this problem, but even soldered joints suffer from corrosion when exposed to weather.

Signs of excess heat are sometimes seen near poor connections in circuits that carry moderate current. The increase in dissipated power at the poor connection heats the contacts, and this leads to more resistance and soon the connection fails. Check for short and open circuits with an ohmmeter or continuity tester. Clean those connections that fail as a result of contamination.

Occasionally, corroded connectors may be repaired by cleaning, but replacement of the conductor/connector is usually required, especially for battery holders supplying moderate currents. Solder all connections that may be subject to harsh environments and protect them with acrylic enamel, RTV compound or a similar coating. An anti-corrosion compound or grease is a good idea for connections located outside. See the entry on Weatherproofing RF Connectors in the Antenna and Tower Safety section of the **Safety** chapter.

Choose replacement connectors with consideration of voltage and current ratings. Use connectors with symmetrical pin arrangements only where correct insertion will not result in a safety hazard or circuit damage.

26.2.5 Resistors

Resistors usually fail by becoming an open circuit. More rarely they change value. Both failures are usually caused by excess heat. Such heat may come from external sources or from power dissipated within the resistor. Sufficient heat burns the resistor until it becomes an open circuit.

Resistors can also fracture and become an open circuit as a result of physical shock. Contamination on or around a high-value resistor (100 kΩ or more) can cause a change in value by providing a leakage path for current around a resistor. This contamination can occur on the resistor body, mounts or printed-circuit board. Resistors that have changed value should be replaced. Leakage is cured by cleaning the resistor body and surrounding area.

In addition to the problems of fixed-value resistors, potentiometers and rheostats can develop noise problems, especially in dc circuits. Dirt often causes intermittent contact between the wiper and resistive element. To cure the problem, spray electronic contact cleaner into the control, through holes in the case, and rotate the shaft a few times.

The resistive element in wire-wound potentiometers eventually wears and breaks from the sliding action of the wiper. In this case, the control needs to be replaced.

Replacement resistors should be of the same value, tolerance, type and power rating as the original. The value should stay within tolerance. Replacement resistors may be of a different type than the original, if the characteristics of the replacement are consistent with circuit requirements. (See the **Electrical Fundamentals** chapter for more information on resistor types.)

Substitute resistors can usually have a greater power rating than the original, except in high-power emitter circuits where the resistor also acts as a fuse, or in cases where the larger size presents a problem.

Variable resistors should be replaced with the same kind (carbon or wire wound) and taper (linear, log, reverse log and so on) as the original. Keep the same, or better, tolerance and pay attention to the power rating.

In all cases, mount high-temperature resistors away from heat-sensitive components. Keep carbon composition and film resistors away from heat sources. This will extend their life and ensure minimum resistance variations.

26.2.6 Capacitors

Capacitors usually fail by shorting, opening or becoming electrically (or physically) leaky. They rarely change value. Capacitor failure is usually caused by excess current, voltage, temperature or aging of the dielectric or materials making up the capacitor. Leakage can be external to the capacitor (contamination on the capacitor body or circuit) or internal to the capacitor.

TESTS

If you do not have a multimeter with a capacitor test function or a component tester, the easiest way to test capacitors is out of circuit with an ohmmeter. In this test, the resistance of the meter forms a timing circuit with the capacitor to be checked. Capacitors from 0.01 µF to a few hundred µF can be tested with common ohmmeters. Set the meter to its highest range and connect the test leads across the discharged capacitor. When the leads are connected, current begins to flow. Current is high when the capacitor is discharged, but drops as the capacitor voltage builds up. This shows on the meter as a low resistance that builds, over time, toward infinity.

The speed of the resistance build-up corresponds to capacitance. Small capacitance values approach infinite resistance almost instantly. A 0.01 µF capacitor checked with a meter having an 11 MΩ input impedance would increase from zero to a two-thirds scale reading in 0.11 second, while a 1 µF unit would require 11 seconds to reach the same reading. If the tested capacitor does not reach infinity within five times the period taken to reach the two-thirds point, it has excess leakage. If the meter reads infinite resistance immediately, the capacitor is open. (Aluminum electrolytics normally exhibit high-leakage readings.)

Capacitance can also be measured for approximate value with a dip meter by constructing a parallel-resonant circuit using an inductor of known value. The formula for resonance is discussed in the **Electrical Fundamentals** chapter of this book.

It is good practice to keep a collection of known components that have been measured on accurate L or C meters. Alternatively, a standard value can be obtained by ordering 1 or 2% components from an electronics supplier. A 10% tolerance component can be used as a standard; however, the results will be known only to within 10%. The accuracy of tests made with any of these alternatives depends on the accuracy of the standard value component. Further information on this technique appears in Bartlett's article, "Calculating Component Values," in Nov 1978 *QST*.

Older capacitors can also be checked and the dielectric reformed, if necessary, with a capacitor checker of similar vintage. See this chapter's section on Restoration and Repair of Vintage Radios for more information about this technique.

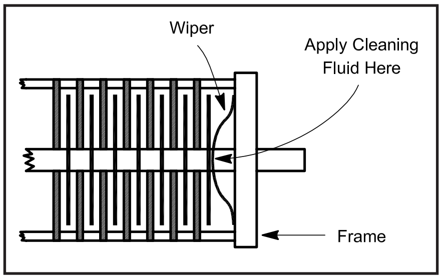

Figure 26.8 — Partial view of an air-dielectric variable capacitor. If the capacitor is noisy or erratic in operation, apply electronic cleaning fluid where the wiper contacts the rotor plates.

CLEANING

The only variety of common capacitor that can be repaired is the air-dielectric variable capacitor. Electrical connection to the moving plates is made through a spring-wiper arrangement (see **Figure 26.8**). Dirt normally builds on the contact area, and it needs occasional cleaning. Before cleaning the wiper/contact, use gentle air pressure and a soft brush to remove all dust and dirt from the capacitor plates. Apply some electronic contact cleaning fluid. Do not lubricate the contact point. Rotate the shaft quickly several times to work in the fluid and establish contact. Use the cleaning fluid sparingly and keep it off the plates except at the contact point.

REPLACEMENTS

Replacement capacitors should match the original in value, tolerance, dielectric, working voltage and temperature coefficient. Use only ac-rated capacitors for line service (capacitors connected directly to the ac line) to prevent fire hazards. If exact replacements are not available, substitutes may vary from the original part in the following respects: bypass capacitors may vary from one to three times the capacitance of the original, coupling capacitors may vary from one-half to twice the value of the original, capacitance values in tuned circuits (especially filters) must be exact (even then, any replacement will probably require circuit realignment).

If the same kind of capacitor is not available, use one with better dielectric characteristics. Do not substitute polarized capacitors for non-polarized parts. Capacitors with a higher working voltage may be used, although the capacitance of an electrolytic capacitor used significantly below its working voltage will usually increase with time.

The characteristics of each type of capacitor are discussed in the **Electrical Fundamentals** and **RF Techniques** chapters. Consider these characteristics if you're not using an exact replacement capacitor.

Batteries and Tools

When working on equipment powered by a battery with a capacity of more than a few ampere-hours (Ah), take special care to avoid short circuits and always have a fuse or circuit-breaker in-line to the battery. If possible, fuse both the positive and negative connections. This is particularly important for vehicle batteries and mobile equipment. A short circuit can do thousands of dollars of damage to a vehicle's electrical power system in a matter of seconds! When working on mobile equipment, disconnect the battery's positive terminal or at least disconnect the circuit that powers the equipment by removing the fuse.

A tool that accidentally short circuits the battery terminals can cause an instantaneous current flow of thousands of amps, often destroying both the battery and the tool and creating a significant fire and burn hazard.

26.2.7 Inductors and Transformers

The most common inductor or transformer failure is a broken conductor. More rarely, a short circuit can occur across one or more turns of a coil. In an inductor, this changes the value. In a transformer, the turns ratio and resultant output voltage changes. In high-power circuits, excessive inductor current can generate enough heat to melt plastics used as coil forms.

Inductors may be checked for open circuit failure with an ohmmeter. In a good inductor, dc resistance rarely exceeds a few ohms. Shorted turns and other changes in inductance show only during alignment or inductance measurement.

The procedure for measurement of inductance with a dip meter is the same as that given for capacitance measurement, except that a capacitor of known value is used in the resonant circuit.

Replacement inductors must have the same inductance as the original, but that is only the first requirement. They must also carry the same current, withstand the same voltage and present nearly the same Q as the original part. Given the original as a pattern, the amateur can duplicate these qualities for many inductors. Note that inductors with ferrite or iron-powder cores are frequency sensitive, so the replacement must have the same core material.

If the coil is of simple construction, with the form and core undamaged, carefully count and write down the number of turns and their placement on the form. Also note how the coil leads are arranged and connected to the circuit. Then determine the wire size and insulation used. Wire diameter, insulation and turn spacing are critical to the current and voltage ratings of an inductor. (There is little hope of matching coil characteristics unless the wire is duplicated exactly in the new part.) Next, remove the old winding — be careful not to damage the form — and apply a new winding in its place. Be sure to dress all coil leads and connections in exactly the same manner as the original. Apply Q dope (a solution of polystyrene plastic) or a thin coating of plastic-based glue to hold the finished winding in place.

Follow the same procedure in cases where the form or core is damaged, except that a suitable replacement form or core (same dimensions and permeability) must be found.

Ready-made inductors may be used as replacements if the characteristics of the original and the replacement are known and compatible. Unfortunately, many inductors are poorly marked. If so, some comparisons, measurements and circuit analysis are usually necessary.

When selecting a replacement inductor, you can usually eliminate parts that bear no physical resemblance to the original part. This may seem odd, but the Q of an inductor depends on its physical dimensions and the permeability of the core material. Inductors of the same value, but of vastly different size or shape, will likely have a great difference in Q. The Q of the new inductor can be checked by installing it in the circuit, aligning the stage and performing the manufacturer's passband tests. Although this practice is all right in a pinch, it does not yield an accurate Q measurement. Methods to measure Q appear in the **Test Equipment and Measurements** chapter.

Once the replacement inductor is found, install it in the circuit. Duplicate the placement, orientation and wiring of the original. Ground-lead length and arrangement should not be changed. Isolation and magnetic shielding can be improved by replacing solenoid inductors with toroids. If you do, however, it is likely that many circuit adjustments will be needed to compensate for reduced coupling and mutual inductance. Alignment is usually required whenever a tuned-circuit component is replaced.

A transformer consists of two inductors that are magnetically coupled. Transformers are used to change voltage and current levels (this changes impedance also). Failure usually occurs as an open circuit or short circuit of one or more windings. Insulation failures can also occur that result in short circuits between windings or between windings and the core or case. It is also common for the insulated wire leads to develop cracks or abrasion where they come out of the case. This can be repaired easily by replacing the lead, or if the conducting wire strands are not burned or broken, by sliding an insulation sleeve over the wire to protect the insulation from further wear.

Amateur testing of power transformers is mostly limited to ohmmeter tests for open circuits and voltmeter checks of secondary voltage. Make sure that the power-line voltage is correct, then check the secondary voltage against that specified. There should be less than 10% difference between open-circuit and full-load secondary voltage. A test setup and procedure for evaluating power transformers is also provided in the **Power Sources** chapter.

Replacement transformers must match the original in voltage, volt-ampere (VA), duty cycle and operating-frequency ratings. They must also be compatible in size. (All transformer windings should be insulated for the full power supply voltage.)

When disconnecting a transformer for testing or repair, be sure to carefully record the color and connection for each of the transformer leads. In power transformers it is common for leads to be mostly one color, but with a contrasting stripe or other pattern that can be overlooked. If in doubt, use tape or paper labels to note the connection for each lead. Recording transformer color codes and connections is a good use of the shack notebook.

26.2.8 Relays

Although relays have been replaced by semiconductor switching in low-power circuits, they are still used extensively in high-power amateur radio equipment for applications such as amplifier TR switching and in antenna systems or ac power control. Relay action may become sluggish. AC relays can buzz (with adjustment becoming impossible). A binding armature or weak springs can cause intermittent switching. Excessive use or hot switching ruins contacts and shortens relay life.

You can test relays with a voltmeter by measuring voltage across contacts (power on, in-circuit) or with an ohmmeter (out of circuit). Look for erratic readings across the contacts, open or short circuits at contacts, or an open circuit at the coil. A visual inspection with a magnifying glass should show no oxidation or corrosion. Limited pitting is usually OK.

Most failures of simple relays can be repaired by a thorough cleaning. Clean the contacts and mechanical parts with a residue-free cleaner. Keep it away from the coil and plastic parts that may be damaged. Dry the contacts with lint-free paper, such as a business card, then burnish them with a smooth steel blade. Do not use a file to clean contacts because it will damage the contact surface.

Replacement relays should match or exceed the original specifications for voltage, current, switching time and stray impedance (impedance is significant in RF circuits only). Many relays used in transceivers are specially made for the manufacturer. Substitutes may not be available from any other source.

Before replacing a multi-contact relay, make a drawing of the relay, its position, and the leads and their routings through the surrounding parts. This drawing allows you to complete the installation properly, even if you are distracted in the middle of the operation. (This is a good use of the shack notebook!)

26.2.9 Semiconductors

Testing diodes and transistors with the ohmmeter function of an analog VOM used to be the normal method. Today's inexpensive multimeters nearly always provide a forward and reverse junction voltage drop test function. This almost eliminates the need for resistance-based tests for functional troubleshooting with the attendant variability and dependence on meter circuits. However, it is occasionally useful to perform threshold and voltage-current testing to match components or troubleshoot a specialized circuit. In support of those tests, the short article "Diode and Transistor Test Circuits" containing test circuits and procedures for measuring leakage, gain, Zener point voltage and so forth is included with the downloadable supplemental content. This section will focus on simple go/no-go testing.

DIODES

The primary function of diodes is to pass current in one direction only. They can be easily tested with an ohmmeter, and most multimeters have a diode junction test function built-in as well.

Signal or switching diodes — The most common diode in electronics equipment, signal diodes, are used to convert ac to dc, to detect RF signals or to take the place of relays to switch ac or dc signals within a circuit. Signal diodes usually fail open, although shorted diodes are not rare.

Power rectifiers — Most equipment contains a power supply, so power rectifier diodes are the second-most common diodes in electronic circuitry. They usually fail shorted, blowing the power-supply fuse.

Other diodes — Zener diodes are made with a predictable reverse-breakdown voltage and are used as voltage regulators. Varactor diodes are specially made for use as voltage controlled variable capacitors. (Any semiconductor diode may be used as a voltage-variable capacitance, but the value will not be as predictable as that of a varactor.) A diac is a special-purpose diode that passes only pulses of current in each direction.

Diode testing — There are several basic tests for most diodes. First, is it a diode? Does it conduct in one direction and block current flow in the other? A simple resistance measurement is suitable for this test in most cases.

Diodes should be tested out of circuit. Disconnect one lead of the diode from the circuit, then perform the test. Diodes can also be tested by measuring the voltage drop across the diode junction while the diode is conducting.

A functioning diode will show high resistance in one direction and low resistance in the other. A DMM with a diode-test function is the best instrument to use. If using an analog meter, make sure to use more than 0.7 V and less than 1.5 V to measure resistance. Use the highest resistance scale of the meter that gives a reading of less than full-scale. Check a properly functioning diode to determine the meter polarity if there is any question. Compare the forward and reverse resistance readings for a properly functioning diode to those of the diode being tested to determine whether the diode is good.

Diode junction forward voltage drops are measured by a multimeter's diode test function. Silicon junctions usually show about 0.6 V at typical test current levels, while germanium is typically 0.2 V. Junction voltage drop increases with current flow.

Multimeters measure the junction resistances at low voltage and are not useful for testing Zener diodes. A good Zener diode will not conduct in the reverse direction at voltages below its rating. See the article included with the downloadable supplemental content, and mentioned at the beginning of this section, for procedures and a circuit to determine Zener diode performance.

Replacement diodes — When a diode fails, check associated components as well. Replacement rectifier diodes should have the same current and peak inverse voltage (PIV) as the original. Series diode combinations are often used in high-voltage rectifiers. (The resistor and capacitor networks used to distribute the voltage equally among the diodes are no longer required for new rectifiers but should be retained for older parts. See the **Power Sources** chapter for more information.)

Switching diodes may be replaced with diodes that have equal or greater current ratings and a PIV greater than twice the peak-to-peak voltage encountered in the circuit. Switching time requirements are not critical except in RF, logic and some keying circuits. Logic circuits may require exact replacements to assure compatible switching speeds and load characteristics. RF switching diodes used near resonant circuits must have exact replacements, as the diode resistance and capacitance will affect the tuned circuit.

Voltage and capacitance characteristics must be considered when replacing varactor diodes. Once again, exact replacements are best. Zener diodes should be replaced with parts having the same Zener voltage and equal or higher power rating, and equal or lower tolerance. Check the associated current-limiting resistor when replacing a Zener diode.

BIPOLAR TRANSISTORS

Transistor failures occur as an open junction, a shorted junction, excess leakage or a change in amplification performance. Most transistor failure is catastrophic. A transistor that has no leakage and amplifies at dc or audio frequencies will usually perform well over its design range. For this reason, transistor tests need not be performed at the planned operating frequency. Tests are made at dc or a low frequency (usually 1000 Hz). The circuit under repair is the best test of a potential replacement part. Swapping in a replacement transistor in a failed circuit will often result in a cure.

A simple and reliable test of bipolar transistors can be performed with the transistor in a circuit and the power on. It requires a test lead, a 10 kΩ resistor and a voltmeter. Connect the voltmeter across the emitter/collector leads and read the voltage. Then use the test lead to connect the base and emitter (**Figure 26.9A**). Under these conditions, conduction of a good transistor will be cut off and the meter should show nearly the entire supply voltage across the emitter/collector leads. Next, remove the clip lead and connect the 10 kΩ resistor from the base to the collector. This should bias the transistor into conduction, and the emitter/ collector voltage should drop (Figure 26.9B). (This test indicates transistor response to changes in bias voltage.)

Transistors can be tested (out of circuit) with an ohmmeter in the same manner as diodes, or a multimeter with a transistor test function can be used. Before using the ohmmeter-transistor circuit, look up the device characteristics before testing and consider possible consequences of testing the transistor in this way. Limit junction current to 1 to 5 mA for small-signal transistors. Transistor destruction or inaccurate measurements may result from careless testing.

The reverse-to-forward resistance ratio for good transistors may vary from 30:1 to better than 1,000 1. Germanium transistors — still occasionally encountered — sometimes show high leakage when tested with an ohmmeter. Bipolar transistor leakage may be specified from the collector to the base, emitter to base or emitter to collector (with the junction reverse biased in all cases). The specification may be identified as I_{cbo}, I_{bo}, collector cutoff current or collector leakage for the base-collector junction, I_{ebo}, and so on for other junctions. Leakage current increases with junction temperature. (See the **Circuits and Components** chapter for definitions of these and other transistor parameters.)

While these simple test circuits will identify most transistor problems, RF devices should be tested at RF. Most component manufacturers include a test-circuit schematic on the data sheet. The test circuit is usually an RF amplifier that operates near the high end of the device frequency range. If testing at RF is not possible, substitution of a properly functioning device is required.

Semiconductor failure is sometimes the result of environmental conditions. Open junctions, excess leakage (except with germanium transistors) and changes in amplification performance result from overload or excessive current.

Cross-Reference Replacement Semiconductors

Semiconductors from older equipment, even ICs, may be available as a cross-reference generic replacement. The primary source for these devices is NTE Electronics (**www.nteinc.com**). Enter the part number of the device you are trying to replace in the "Cross-Reference" window. NTE also supplies cross-referenced replacements for ECG part numbers that were the original generic replacement parts.

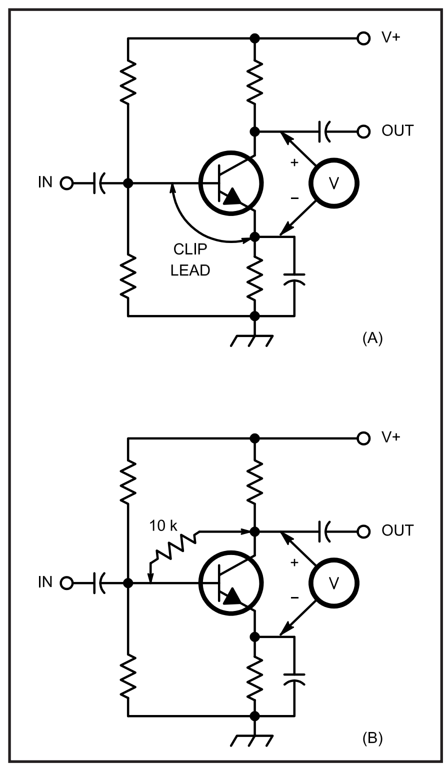

Figure 26.9 — An in-circuit semiconductor test with a clip lead, resistor and voltmeter. The meter should read V+ at (A). During test (B) the meter should show a decrease in voltage, ranging from a slight variation down to a few millivolts. It will typically cut the voltage to about half of its initial value.

Shorted junctions (low resistance in both directions) are usually caused by voltage spikes. Electrostatic discharge (ESD) or transients from lightning can destroy a semiconductor in microseconds.

Transistors rarely fail without an external cause. Check the surrounding parts for the cause of the transistor's demise, and correct the problem before installing a replacement.

JFETs

Junction FETs can be tested with a multimeter's diode junction test function in much the same way as bipolar transistors (see text and **Figure 26.10**). Reverse leakage should be several megohms or more. Forward resistance should be 500 to 1000 Ω if measured with an analog meter.

MOSFETs

Small-signal MOS (metal-oxide semiconductor) layers are extremely fragile. Normal body static is enough to damage them. Even gate protected (a diode is placed across the MOS layer to clamp voltage) MOSFETs may be destroyed by a few volts of static electricity. MOSFETs used for power circuits and RF amplifiers are much more resistant to damage. The manufacturer's sheet will specify any special static-protection measures that are required. (See the **Construction Techniques** chapter for more information about managing static at the workbench.)

When testing small MOSFETs make sure the power is off, capacitors, discharged and the leads are shorted together before installing or removing it from a circuit. Use a voltmeter to be sure the chassis is near ground potential, then touch the chassis before and during MOSFET installation and removal. This assures that there is no difference of potential between your body, the chassis and the MOSFET leads. Ground the soldering-iron tip with a clip lead when soldering MOS devices. The FET source should be the first lead connected to and the last disconnected from a circuit. The insulating layers in MOSFETs prevent testing with an ohmmeter. Substitution is the only practical means for amateur testing of MOSFETs.

FET CONSIDERATIONS

Replacement FETs should be of the same type as the original part: JFET or MOSFET, P-channel or N-channel, enhancement or depletion. Consider the breakdown voltage required by the circuit. The breakdown voltage should be at least two to four times the power-supply and signal voltages in amplifiers. Allow for transients of 10 times the line voltage in power supplies. Breakdown voltages are usually specified as $V_{(BR)GSS}$ or $V_{(BR)GDO}$.

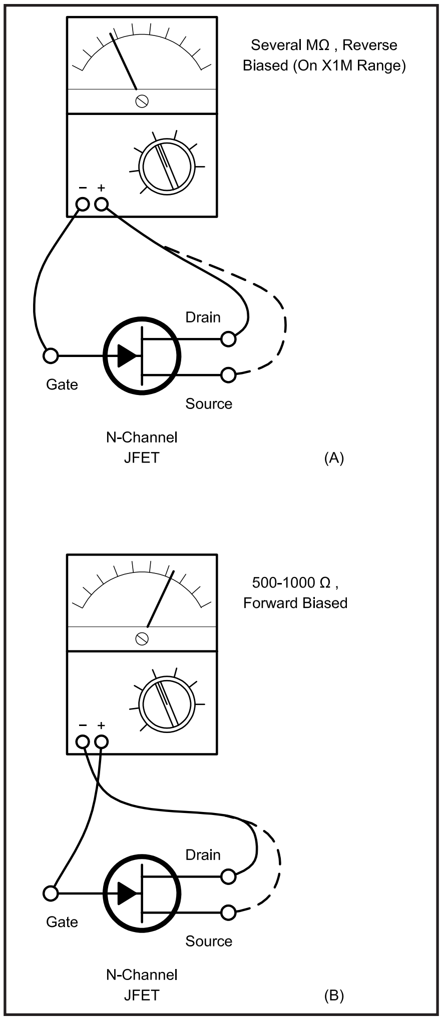

Figure 26.10 — Ohmmeter tests of a JFET. The junction is reverse biased at A and forward biased at B. (Analog meters are shown for convenience of illustration.)

The gate-voltage specification gives the gate voltage required to cut off or initiate channel current (depending on the mode of operation). Gate voltages are usually listed as $V_{GS(OFF)}$, V_p (pinch off), V_{TH} (threshold) or $I_{D(ON)}$ or I_{TH}.

Dual-gate MOSFET characteristics are more complicated because of the interaction of the two gates. Cutoff voltage, breakdown voltage and gate leakage are the important traits of each gate.

INTEGRATED CIRCUITS

The basics of integrated circuits are covered in earlier chapters of this book. Amateurs seldom have the sophisticated equipment required to test ICs. Even a multi-channel oscilloscope can view only their simplest functions. We must be content to check every other possible cause, and only then assume that the problem lies with an IC. Experienced troubleshooters will tell you that — most of the time anyway — if a defective circuit uses an IC, it is the IC that is bad.

Linear ICs — There are two major classes of ICs: linear and digital. Linear ICs are best replaced with identical units. Original equipment manufacturers are the best source of a replacement; they are the only source with a reason to stockpile obsolete or custom-made items. If substitution of an IC is unavoidable, first try the cross-reference website of NTE mentioned in the sidebar. You can also look in manufacturers' websites and compare pinouts and other specifications.

Digital ICs — It is usually not a good idea to substitute digital devices. While it may be okay to substitute an AB74LS00YZ from one manufacturer with a CD74LS00WX from a different manufacturer, you will usually not be able to replace an LS (low-power Schottky) device with an S (Schottky), C (CMOS), or any of a number of other families. The different families all have different speed, current-consumption, input and output characteristics. You would have to analyze the circuit to determine if you could substitute one type for another.

SEMICONDUCTOR SUBSTITUTION

In all cases try to obtain exact replacement semiconductors. Specifications vary slightly from one manufacturer to the next. Cross-reference equivalents such as NTE (**www.nteinc.com**) are useful but not guaranteed to be an exact replacement. Before using an equivalent, check the specifications against those for the original part. When choosing a replacement, consider:

- Is it a PNP or an NPN?
- What are the operating frequency and input/output capacitance?
- How much power can it dissipate (often less than Vmax × Imax)?
- Will it fit the original socket or pad layout?
- Are there unusual circuit demands (low noise and so on)?
- What is the frequency of operation?

Remember that cross-reference equivalents are not guaranteed to work in every application. In cases where an absolutely exact replacement is required for an obsolete part, Rochester Electronics (**www.rocelec.com**) or 4 Star Electronics (**www.4starelectronics.com**) maintain extensive stocks, although the cost is likely to be rather high.

There may be cases where two dissimilar devices have the same part number, so it pays to compare the listed replacement specifications with the intended use. If the book says to use a diode in place of an RF transistor, it isn't going to work! Derate power specifications, as recommended by the manufacturer, for high-temperature operation.

26.2.10 Tubes

The most common tube failures in amateur service are caused by cathode depletion and gas contamination. Whenever a tube is operated, the coating on the cathode loses some of its ability to produce electrons. It is time to replace the tube when electron production (cathode current, I_c) falls to 50 to 60% of that exhibited by a new tube.

Gas contamination in a tube can often be identified easily because there may be a greenish or whitish-purple glow between the elements during operation. (A faint deep-purple glow is normal in most tubes.) The gas reduces tube resistance and leads to runaway plate current evidenced by a red glow from the anode, interelectrode arcing or a blown power supply fuse. Less common tube failures include an open filament, broken envelope and inter-electrode shorts.

The best test of a tube is to substitute a new one. Another alternative is a tube tester; these are sometimes available at hamfests or through antique radio or audiophile groups. You can also do some limited tests with an ohmmeter. Tube tests should be made out of circuit so circuit resistance does not confuse the results.

Use an ohmmeter to check for an open filament (remove the tube from the circuit first). A broken envelope is visually obvious, although a cracked envelope may appear as a gassy tube. Interelectrode shorts are evident during voltage checks on the operating stage. Any two elements that show the same voltage are probably shorted. (Remember that some inter-electrode shorts, such as the cathode-suppressor grid, are normal.)

Generally, a tube may be replaced with another that has the same type number. Compare the data sheets of similar tubes to assess their compatibility. Consider the base configuration and pinout, inter-electrode capacitances (a small variation is okay except for tubes in oscillator service), dissipated power ratings of the plate and screen grid and current limitations (both peak and average). For example, the 6146A may usually be replaced with a 6146B (heavy duty), but not vice versa.

In some cases, minor type-number differences signify differences in filament voltages, or even base styles, so check all specifications before making a replacement. (Even tubes of the same model number, prefix and suffix vary slightly, in some respects, from one supplier to the next.)

26.3 Getting Started

INSTINCTIVE OR SYSTEMATIC

A systematic approach to troubleshooting uses a defined process to analyze and isolate the problem. An instinctive approach relies on troubleshooting experience to guide you in selecting which circuits to test and which tests to perform.

When instinct is based on experience, searching by instinct may be the fastest procedure. If your instinct is correct, repair time and effort may be reduced substantially. As experience and confidence grow, the merits of the instinctive approach grow with them. However, inexperienced technicians who choose this approach are at the mercy of chance.

A systematic approach is a disciplined procedure that allows us to tackle problems in unfamiliar equipment with a reasonable hope of success. The systematic approach is usually chosen by beginning troubleshooters.

26.3.1 The Systematic Approach

Armed with a collection of test equipment, you might be tempted to immediately dig in and start looking for the problem. While it is sometimes obvious what piece of equipment or subassembly inside equipment is at fault, the many connections that make up nearly all ham stations today make it far more effective to begin troubleshooting by looking at the problem from the system perspective. By *system*, we mean more than one piece of equipment or subassemblies connected together — nothing fancier than that.

Amateur stations are full of systems: a digital mode system is made up of a radio, power supply, and PC. An antenna system consists of the antenna tuner, feed line, and antenna. Inside a radio there is a system made up of the power circuits, receiver, transmitter, control panel, and transmit-receive switching circuits. Connections between parts of the system need not be cables; wireless data links can also be part of a system.

In general, it's best to approach any problem — even the supposedly obvious problems — from the perspective of the system it affects. The first step is to determine the system with the smallest number of components that exhibit the problem. Then you can start looking for the problem in one of those components or the connection between them. We'll start with an example to illustrate the process.

Problem — After a year of trouble-free operation, when you transmit with more than 50 W of output power using PSK31, other stations now report lots of distortion products around your signal on the waterfall display, even though the ALC is not active at all and no software level settings have been changed. This could be RF interference, a problem with the digital interface between the PC and the radio, settings in the PC, settings in the radio, a bad connection...there are lots of possibilities.

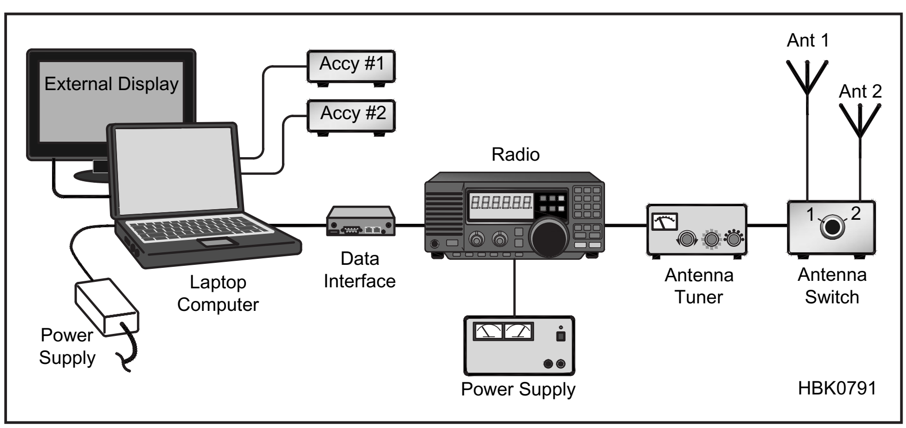

Figure 26.11 — The complete system of radio and power supply, data interface, laptop PC with a couple of accessories (Accy) and power supply, antenna tuner, antenna switch, antenna 1 and 2, and interconnecting cables.

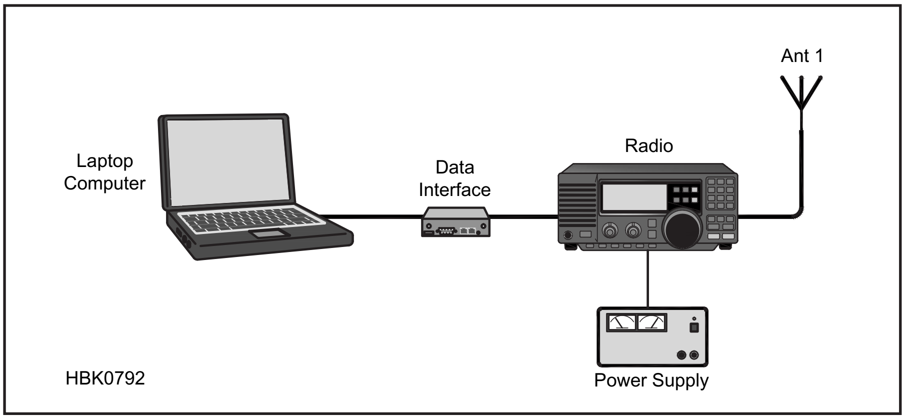

Figure 26.12 — The minimum system of radio and power supply, digital interface, laptop on battery power, antenna 1, and interconnecting cables.

Read the Manual!

Your equipment may be working as designed. Many electronic "problems" are caused by a switch or control in the wrong position, a misconfigured menu item, or a unit that is being asked to do something it was not designed to do. Before you open up your equipment for major surgery, make sure you are using it correctly. Most user's manuals have a procedure for setting up the equipment initially and for performing partial and full resets of microprocessor-controlled gear.

Get a pad of paper and sketch out the system that is exhibiting the problem, such as in **Figure 26.11**. Write down what the symptom(s) is (are) and the conditions under which they occur. Figure 26.11 shows that you have a system that has a lot of parts involved, including the interconnecting cables. Let's simplify that system! For this type of problem, it would be very helpful to have a friend available to listen on the air as you troubleshoot. To find the minimum system, start by removing any accessories that aren't being used from the radio and PC and trying to reproduce the problem, writing down each step and noting whether the problem changed. Not only will you simplify the problem but in the process you will have an excellent opportunity to inspect and check connections and configurations — perhaps even discovering the problem!

Let's say that the distortion persists with the mouse and external display disconnected and the laptop running from its internal battery. Then you were able to remove the antenna tuner and antenna switch, manually attaching just one antenna to the radio at a time, and found that the problem only occurred when using antenna 1. Removing any other part of the system makes it non-functional, so you have found the minimum system with the problem as shown in **Figure 26.12**.

Now it's time to start making small changes in the minimum system to observe the effect, again taking notes as you go. Changing the microphone gain a little bit up and down has hardly any effect. Changing the PC sound card output audio level a little bit also has hardly any effect. Reducing RF output power a little bit has a *big* effect: as power is reduced, so are the distortion products. Below 35 W, the problem was completely gone! This is an important clue, dutifully recorded on the pad of paper. Replacing antenna 1 with a dummy load had a similar effect — the problem disappeared according to your friend, who lives close enough to hear the weak signal leaking out of your greatly reduced antenna system. Putting antenna 1 back on the radio causes the problem to come back above 35 W, too.

The behavior of the problem points strongly to RF being picked up by a cable in your minimum system and interfering with the low-level digital audio. It's time for a close inspection of each remaining cable. Removing the radio's microphone connector shell and checking the wires inside didn't turn up anything — all of the connections were intact and only touching what they were supposed to touch. Looking at the cable between the digital interface and the sound card, though, you see that the shield of the cable at the PC end is badly frayed and barely making contact at all! In a few minutes, you've trimmed and re-soldered the cable, plugging it back into the PC. Testing even at full power output shows no distortion products on either antenna.

You fixed the problem by finding the minimum system and then inspecting one thing at a time until the root cause was found and eliminated.

What if the root cause didn't appear when you checked the cables? Then you would have to continue to test the system at the interfaces where the system components are connected together. You could measure signal levels with a sensitive voltmeter. You could add ferrite beads or cores on cables that might be picking up RF. You could check to see if the radio's power supply output is stable and clean as the transmitter power increases.

Another strategy would be to substitute known good components, one at a time, and see if the problem changes or disappears: you might swap in a different data interface, you could change the cables; or try a different power supply or radio or laptop.

Most systematic testing combines direct testing or inspection and a process of substitution. The goal is to either find the root cause or find the system component in which the root cause is hiding. Once you have identified system component as the culprit, treat the component as a system itself and start the process all over again. Eventually, you'll find the problem.

Here are some guidelines to systematic troubleshooting in the ham shack:

1. Take the time to define and understand the system exhibiting the problem.
2. Remove system components one at a time.
3. Verify that the problem still exists. If not, restore that component.
4. Continue to remove components and test until the minimum system exhibiting the problem has been reached.
5. Inspect what is happening at each interface between system components by testing or substitution. In the example, you inspected the cables connecting the radio and other system components.
6. If a problem is identified, correct it and re-test.
7. Otherwise, continue to test or substitute each system component until the root cause has been identified or isolated to one component.
8. Treat that component as a new system and return to step 1.

Systematically reducing the number of components and testing each interface between them is almost always the fastest way to determine where the problem's root cause really lies. You may be a lucky guesser and sometimes a little plume of smoke is a dead giveaway, but in the long run the system approach will save you time and money.

26.3.2 Assessing the Symptoms

An important part of the troubleshooting process is a careful definition of just what the symptoms of the problem really are. It is important to note exactly how the problem manifests itself and the conditions under which the problem occurs. Avoid vague descriptions such as "broken" and "not working." Train yourself to use precise descriptions such as "relay fails to activate" or "no speaker output."

Ask yourself these questions:

1. What functions of the equipment do not work as they should; what does not work at all?

2. What kind of performance can you realistically expect?

3. Has the trouble occurred in the past? (Keep a record of troubles and maintenance in the owner's manual, shack notebook or log book.)

Write down the answers to the questions. The information will help with your work, and it may help service personnel if their advice or professional service is required.

Question your assumptions and verify what you think you know. Are you *sure* that power supply output is OK under all conditions? Did you actually confirm that there is continuity at every position of the antenna switch? If there is any doubt, make a confirming measurement or inspection. Countless hours have been wasted because of unjustified assumptions!

Intermittent problems are generally harder to track down, so try to note the conditions under which the problem occurs — those are often important clues.

Troubleshooting is a good reason to do regular maintenance. Not only will you have fewer problems, but when something is just a little off or out of place you are much likelier to notice it. Learn to listen to the little voice in your head noting something out of the ordinary. Don't discount the wild cards that occasionally cause problems.

Occasionally step away from the workbench and relax. Take a walk. Your mind will continue to think about the problem, and you may surprise yourself when you sit back down to work!

If you can bounce ideas off a friend, try explaining the problem and letting the friend ask you questions. It's common for someone else with a different perspective to ask questions you haven't thought of.

> **Newly Constructed Equipment**
>
> What if you built a piece of equipment and it doesn't work? In most repair work, the troubleshooter is aided by the knowledge that the circuit once worked so that it is only necessary to find and replace the faulty part(s). This is not the case with newly constructed equipment.
>
> Repair of equipment with no working history is a special, and difficult, case. You may be dealing with a defective component, construction error or even a faulty design. Carefully checking for these defects can save you hours. This is a good reason to test homebrew equipment at each possible step and on a section-by-section basis, if possible. In that way, you'll know more about what does work if the completed project has a problem.

26.3.3 External Inspection

Inspection is the easiest part of troubleshooting to do, and careful, detailed inspection will often find the problem or a clue that leads to it. Make sure you have some paper to keep notes on as you go so when something occurs to you it can be recorded.

Try the easy things first. If you are able to solve the problem by replacing a fuse or reconnecting a loose cable, you might be able to avoid a lot of effort. Many experienced technicians have spent hours troubleshooting a piece of equipment only to learn the hard way that the on/off switch was set to OFF or the squelch control was set too high, or that they were not using the equipment properly.

Next, make sure that equipment is plugged in, that the ac outlet does indeed have power, that the equipment is switched on and that all of the fuses are good. If the equipment uses batteries or an external power supply, make sure they supply the right voltage under load.

Check that all wires, cables and accessories are working and plugged into the right connectors or jacks. In a system of components it is often difficult to be sure which component or subsystem is bad. Your transmitter may not work on SSB because the transmitter is bad, but it could also be a bad microphone.

Connector faults or misconnections are common. Consider them prime suspects in your troubleshooting detective work. Do a thorough inspection of the connections. Is the antenna connected? How about the speaker, fuses and TR switch? Are transistors and ICs firmly seated in their sockets? Are all interconnection cables sound and securely connected? Are any pins bent or is a connector inserted improperly? Many of these problems are obvious to the eye, so look around carefully.

While you are performing your inspection, don't forget to use all of your senses. Do you smell anything burnt or overheated? Is something leaking electrolyte or oil? Perhaps a component or connector looks overheated and discolored. Is mounting hardware secure?

Once you're done with your inspection, retest the equipment to be sure the problem is still there or note if it has changed in some way.

26.4 Inside the Equipment

At this point, you've determined that a specific piece of equipment has a problem. A visual inspection of all the operating controls and connections hasn't turned up anything, but the problem is still there. It is time to really dig in, take it apart, and fix it!

26.4.1 Documentation

In order to test any piece of equipment, you'll probably need at least a user's manual. If at all possible, locate a schematic diagram and service manual. It is possible to troubleshoot without a service manual, but a schematic is almost indispensable.

The original equipment manufacturer is the best source of a manual or schematic. However, many old manufacturers have gone out of business. Several sources of equipment manuals can be located by a web search or from one of the *QST* vendors that sell equipment needs. In addition K4XL's Boat Anchor Manual Archive (**www2.faculty.sbc.edu/kgrimm/boatanchor**) has hundreds of freely downloadable electronic copies of equipment manuals. If there is a user's group or email list associated with your equipment, a request to the group may turn up a manual and maybe even troubleshooting assistance.

If all else fails, you can sometimes reverse engineer a simple circuit by tracing wiring paths and identifying components to draw your own schematic. By downloading datasheets for the active devices used in the circuit, the pin-out diagrams and applications notes will sometimes be enough to help you understand and troubleshoot the circuit.

THE BLOCK DIAGRAM

An important part of the documentation, the block diagram is a road map. It shows the signal paths for each circuit function. These paths may run together and cross occasionally or not at all. Those blocks that are not in the paths of faulty functions can be eliminated as suspects. Sometimes the symptoms point to a single block and no further search is necessary. In cases where more than one block is suspect, several approaches may be used. Each requires testing a block or stage.

26.4.2 Disassembly

This seemingly simple step can trap the unwary technician. Most experienced service technicians can tell you the tale of the equipment they took apart and were unable to easily put back together. Don't let it happen to you.

Take photos and lots of notes about the way you take it apart. Take notes about each component you remove. Take a photo or make a sketch of complicated mechanical assemblies before disassembly and then record how you disassembled them. It is particularly important to record the position of shields and ground straps.

Write down the order in which you do things, color codes, part placements, cable routings, hardware notes, and anything else you think you might need to reassemble the equipment weeks from now when the back-ordered part comes in.

Put all of the screws and mounting hardware in one place. A plastic jar with a lid works well; if you drop it the plastic is not apt to break, and the lid will keep all the parts from flying around the work area (you will never find them all). It may pay to have a separate labeled container for each subsystem. Paper envelopes and muffin pans also work well.

26.4.3 Internal Inspection

Many service problems are visible if you look for them carefully. Many a technician has spent hours tracking down a failure, only to find a bad solder joint or burned component that would have been spotted in careful inspection of the printed circuit board. Internal inspections are just as important as external inspections.

It is time consuming, but you really need to look at every connector, every wire, every solder joint and every component. A low power magnifying glass or head-mounted magnifier enables you to quickly scan the equipment to look for problems. A connector may have loosened, resulting in an open circuit. You may spot broken wires or see a bad solder joint. Flexing the printed circuit board or tugging on components a bit while looking at their solder joints will often locate a defective solder job. Look for scorched components.

Make sure all of the screws securing the printed circuit board are tight and making good electrical contact. Check for loose screws on chassis-mounted connectors. (Do not tighten any electrical or mechanical adjusting screws or tuning controls, however!) See if you can find evidence of previous repair jobs; these may not have been done properly. Make sure that ICs are firmly seated in sockets if they are used. Look for pins folded underneath the IC rather than inserted into the socket. If you are troubleshooting a newly constructed circuit, make sure each part is of the correct value or type number and is installed correctly.

POWER SUPPLIES

If your careful inspection doesn't reveal anything, it is time to apply power to the unit under test and continue the process. Observe all safety precautions while troubleshooting equipment. There are voltages inside some equipment that can kill you. If you are not qualified to work safely with the voltages and conditions inside of the equipment, do not proceed. See Table 26.1 and the **Safety** chapter.

You may be able to save quite a bit of time if you test the power supply right away. If the power supply is not working at all or not working properly, no other circuit in the equipment can be expected to work properly either. Once the power supply has either been determined to be OK or repaired, you can proceed to other parts of the equipment. Power supply diagnosis is discussed in detail later in this chapter.

With power applied to the equipment, listen for arcs and look and smell for smoke or overheated components. If no problems are apparent, you can move on to testing the various parts of the circuit. For tube equipment, you may want to begin with ac power applied at a reduced voltage as described in the sections on repair of vintage equipment.

26.4.4 Signal Tracing and Signal Injection

There are two common systematic approaches to troubleshooting radio equipment at the block level. The first is signal tracing; the second is signal injection. The two techniques are very similar. Differences in test equipment and the circuit under test determine which method is best in a given situation. They can often be combined.

Both of these approaches are used on equipment that is designed to operate on a signal (RF, audio or data) in a sequence of steps. A

Knowing When to Quit

It is common for experienced repair techs to be given "basket cases" — equipment that the original troubleshooter disassembled but then couldn't reassemble for whatever reason or couldn't find the problem. One of the most important decisions in the troubleshooting process is knowing when to quit. That is, realizing that you are about to go beyond your skills or understanding of the equipment.

If you proceed past this point, the chances of a successful outcome go down pretty quickly. It's far better to ask for help, work with a more knowledgeable friend, or carefully re-assemble the equipment and take it to a repair tech. Don't let your equipment wind up as a box full of partially connected pieces and mounting hardware under the table at the hamfest with a sign that says, "Couldn't fix — make offer!"

Block-Level Testing for DSP and SDR

More and more functions of today's radio equipment are implemented by microprocessor-based digital signal processing, up to and including full SDR with direct digitization of RF signals very close to the antenna input. A look at the PC boards of such a radio show a few large, many-leaded ICs surrounded by control and interface components, power supply circuits, filtering, and transmitter power amplifiers. The individual stages of the classic superheterodyne architecture are nowhere to be seen. How do you troubleshoot such a radio?

Start with the same basic approach as for an older radio — begin at the input or output and work your way towards the "other end" of the radio. In a DSP-based radio, however, you'll rapidly encounter the point at which the signal "goes digital" and disappears into the microprocessor or an analog/digital converter. Jump to the point where the signal returns to analog form on the "other side" of the microprocessor (or PC in the case of most SDR equipment) and resume testing. In this way you can simply treat the microprocessor as one very large stage in the radio. If the problem turns out to be in the surrounding circuitry or in the interface between a PC and the RF circuits, you can troubleshoot it as you would any other piece of equipment.

If the problem turns out to be in the microprocessor or analog/digital converter, in all probability you will have to get a replacement board from the manufacturer. It is possible to replace the converter or processor (if you can obtain the pre-programmed part), but most manufacturers treat the entire circuit board as the lowest-level replaceable component. This makes repair more expensive (or impossible if no replacements are available), but the positive tradeoff is that the microprocessors rarely fail by themselves, resulting in fewer repairs being required in the first place.

transceiver based on the superheterodyne architecture is probably the best example of this type of equipment in the ham shack. Audio equipment is also built this way. More information about the signal injector and signal sources appears in "Some Basics of Equipment Servicing," from February 1982 *QST* (Feedback, May 1982).

Newer equipment that incorporates DSP and specialized or proprietary ICs is much less amenable to stage-by-stage testing techniques. (See the sidebar "Block-Level Testing for DSP and SDR) Nevertheless, the techniques of signal tracing and signal injection are still useful where the signal path is accessible to the troubleshooter.

SIGNAL TRACING

In signal tracing, start at the beginning of a circuit or system and follow the signal through to the end. When you find the signal at the input to a specific stage, but not at the output, you have located the defective stage. You can then measure voltages and perform other tests on that stage to locate the specific failure. This is much faster than testing every component in the unit to determine which is bad.

It is sometimes possible to use over-the-air signals in signal tracing, in a receiver for example. However, if a good signal generator is available, it is best to use it as the signal source. A modulated signal source is best.

Signal tracing is suitable for most types of troubleshooting of receivers and analog amplifiers. Signal tracing is the best way to check transmitters because all of the necessary signals are present in the transmitter by design. Most signal generators cannot supply the wide range of signal levels required to test a transmitter.

Equipment

A voltmeter with an RF probe is the most common instrument used for signal tracing. Low-level signals cannot be measured accurately with this instrument. Signals that do not exceed the junction drop of the diode in the probe will not register at all, but the presence, or absence, of larger signals can be observed.

A dedicated signal tracer can also be used. It is essentially an audio amplifier. (See the downloadable supplemental content for a project to build your own signal tracer.) An experienced technician can usually judge the level and distortion of the signal by ear. You cannot use a dedicated signal tracer to follow a signal that is not amplitude modulated (single sideband is a form of AM). A signal tracer is not suitable for tracing CW signals, FM signals or oscillators. To trace these, you will have to use a voltmeter and RF probe or an oscilloscope.

An oscilloscope is the most versatile signal tracer. It offers high input impedance, variable sensitivity, and a constant display of the traced waveform. If the oscilloscope has sufficient bandwidth, RF signals can be observed directly. Alternatively, a demodulator probe can be used to show demodulated RF signals on a low-bandwidth oscilloscope. Dual-trace scopes can simultaneously display the waveforms, including their phase relationship, present at the input and output of a circuit.

Procedure

First, make sure that the circuit under test and test instruments are isolated from the ac line by internal transformers, an isolation transformer, or operate from battery power. Set the signal source to an appropriate level and frequency for the unit you are testing. For a receiver, a signal of about 100 µV should be plenty. For other circuits, use the schematic, an analysis of circuit function and your own good judgment to set the signal level.

In signal tracing, start at the beginning and work toward the end of the signal path. Switch on power to the test circuit and connect the signal-source output to the test-circuit input. Place the tracer instrument at the circuit input and ensure that the test signal is present. Observe the characteristics of the signal if you are using a scope (see **Figure 26.13**). Compare the detected signal to the source signal during tracing.

Move the test instrument to the output of the next stage and observe the signal. The signal level should increase in amplifier stages and may decrease slightly in other stages. The signal will not be present at the output of a dead stage.

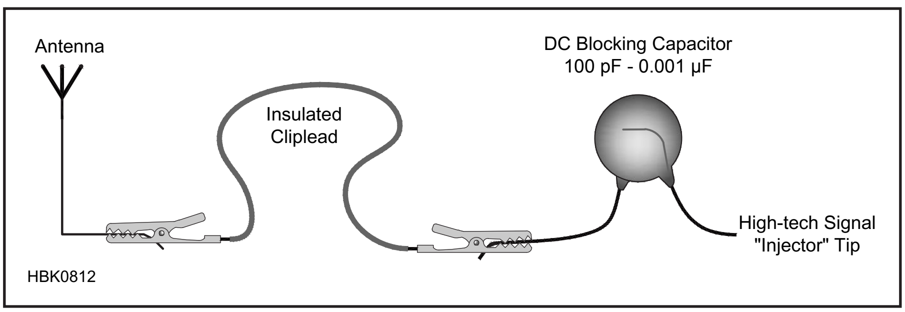

Figure 26.14 — A simple signal injector that uses an antenna to pick up signals to be applied to the circuit under test. [Courtesy Elecraft, www.elecraft.com]

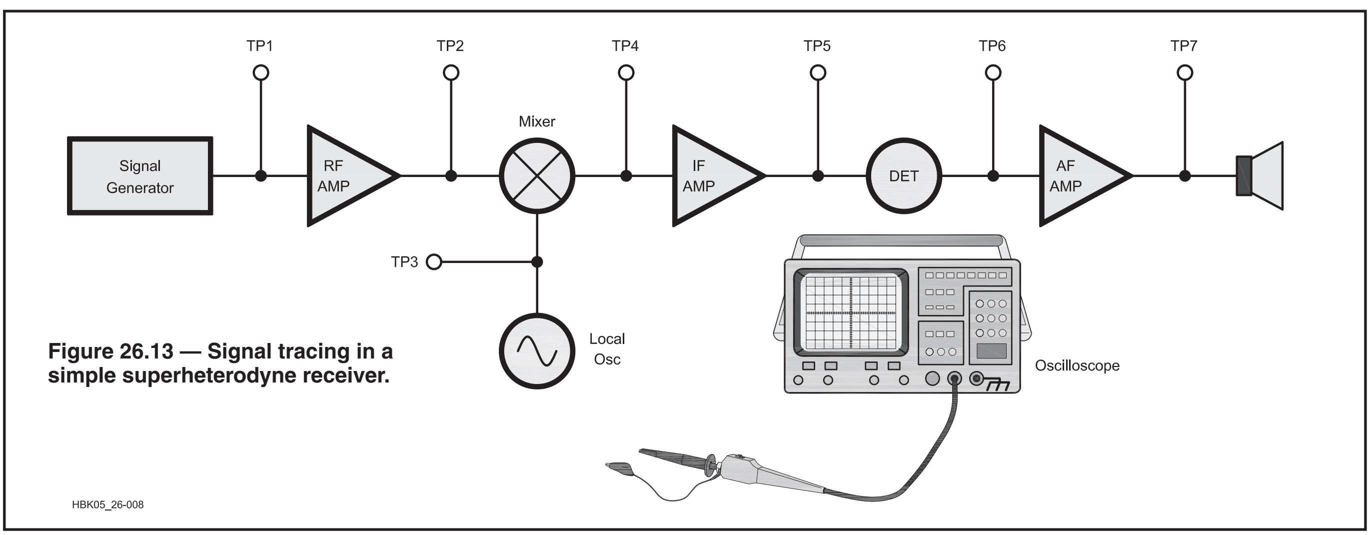

Figure 26.13 — Signal tracing in a simple superheterodyne receiver.

Low-impedance test points may not provide sufficient signal to drive a high-impedance signal tracer, so tracer sensitivity is important. Also, in some circuits the output level appears low where there is an impedance change from input to output of a stage. For example, in a properly-working common-collector (emitter follower) circuit, the input (high-impedance) and output (low-impedance) signals are in phase and have roughly equal voltages. The voltages at TP1 and TP2 are approximately equal and in phase.

There are two signals — the test signal and the local oscillator signal — present in a mixer stage. Loss of either one will result in no output from the mixer stage. Switch the signal source on and off repeatedly to make sure that the test instrument reading varies (it need not disappear) with source switching.

SIGNAL INJECTION

Signal injection is a good choice for receiver troubleshooting because the receiver already has a detector as part of the design. If the detector is working or a suitable detector is devised (see the signal tracing section), a test signal can be injected at different points in the equipment until the faulty stage is discovered.

Equipment

Most of the time, your signal injector will be a signal generator. There are other injectors available, some of which are square-wave audio oscillators rich in RF harmonics (see Figure 26.5). These simple injectors do have their limits because you can't vary their output level or determine their frequency. They are still useful, though, because most circuit failures are caused by a stage that is completely dead.

Consider the signal level at the test point when choosing an instrument. The signal source used for injection must be able to supply appropriate frequencies and levels for each stage to be tested. For example, a typical superheterodyne receiver requires AF, IF and RF signals that vary from 6 V at AF to 200 µV at RF. Each conversion stage used in a receiver requires a different IF from the signal source. When testing the signal path of an AM radio, such as a broadcast receiver, you'll need a modulated RF signal before the detector stage. Use an unmodulated RF signal to simulate the local oscillator.

The simple test circuit of **Figure 26.14** can be used as a quick-and-dirty signal injector for RF stages in a receiver. The antenna can be anything that will receive a signal at the stage's frequency of operation.

Procedure

If an external detector is required, set it to the proper level and connect it to the test circuit. Set the signal source for AF and inject a signal directly into the signal detector to test operation of the injector and detector. Move the signal source to the input of the preceding stage and observe the signal. Continue moving the signal source to the inputs of successive stages.

When you inject the signal source to the input of the defective stage, there will be no output. Prevent stage overload by reducing the level of the injected signal as testing progresses through the circuit. Use suitable frequencies for each tested stage.

Make a rough check of stage gain by injecting a signal at the input and output of an amplifier stage. You can then compare how much louder the signal is when injected at the input. This test may mislead you if there is a radical difference in impedance from stage input to output. Understand the circuit operation before testing.

Mixer stages present a special problem because they have two inputs rather than one. A lack of output signal from a mixer can be caused by either a faulty mixer or a faulty local oscillator (LO). Check oscillator operation with an oscilloscope or by listening on another receiver. If none of these instruments is available, inject the frequency of the LO at the LO output. If a dead oscillator is the only problem, this should restore operation.

If the oscillator is operating but off frequency, a multitude of spurious responses will appear. A simple signal injector that produces many frequencies simultaneously is not suitable for this test. Use a well-shielded signal generator set to an appropriate level at the LO frequency.

> **Divide and Conquer**
>
> If the equipment has a single primary signal path, the block-by-block search may be sped up considerably by testing between successively smaller groups of circuit blocks. Each test thus exercises some fraction of the remaining circuit.
>
> This "divide and conquer" tactic cannot be used in equipment that splits the signal path between the input and the output. Test readings taken inside feedback loops are misleading unless you understand the circuit and the waveform to be expected at each point in the test circuit. It is best to consider all stages within a feedback loop as a single block during the block search.
>
> Divide-and-conquer is a good tactic for those inclined to take the instinctive approach to troubleshooting. As you gain more experience, you'll find yourself able to quickly isolate problems this way. You can then test each block in more detail.

26.4.5 Microprocessor-Controlled Equipment

The majority of today's amateur equipment and accessories have at least one microprocessor and sometimes several. While reliability of this equipment is greatly improved over the older analog designs, troubleshooting microprocessor-based circuitry takes a different approach. While a tutorial on microprocessor troubleshooting is well outside the scope of this *Handbook*, the following basic guidelines will help determine whether the problem is inside the microprocessor (or its firmware) or in the supporting circuitry. In addition, the downloadable **Digital Basics** chapter contains lots of information about the operation of digital circuits.

1) Start by obtaining the microprocessor datasheet and identifying all of the power and control pins if they are not identified on the equipment schematic. Determine which state the control pins should be in for the device to run.

2) Test all power and control pins for the proper state (voltage). Verify that the microprocessor clock signal is active. If not, determine the reason and repair before proceeding.

3) If there is an address and data bus for external memory and input-output (I/O) devices (less common in newer equipment), use a logic probe or scope to verify that they are all active (changing state). If not, there is a program or logic fault.

4) Determine which pins are digital inputs or outputs of the microprocessor and verify that a valid digital logic level exists at the pin. If not, check the external circuit to which the pin is attached.

5) Determine which pins are analog inputs or outputs of the microprocessor. Analyze the external circuit to determine what constitutes a proper voltage into or out of the processor. If the voltage is not valid, check the external circuit to which the pin is attached. If an external voltage reference is used, verify that it is working.

6) External circuits can often be checked by disconnecting them from the microprocessor and either driving them with a temporary voltage source or measuring the signal they are attempting to send to the microprocessor.

7) If all control and power signals and the external circuitry checks out OK, it is likely that a microprocessor or firmware fault has occurred.

If you determine that the microprocessor is faulty, you will have to contact the manufacturer in most cases, since firmware is most often contained within the processor, which must be programmed before it is installed. Older equipment in which the program and data memory are external to the microprocessor can be very difficult to repair due to obsolescence of the parts themselves and the requirement to program EPROM or PROM devices.

26.5 Testing at the Circuit Level

Once you have followed all of the troubleshooting procedures and have isolated your problem to a single defective stage or circuit, a few simple measurements and tests will usually pinpoint one or more specific components that need adjustment or replacement.

First, check the parts in the circuit against the schematic diagram to be sure that they are reasonably close to the design values, especially in a newly built circuit. Even in a commercial piece of equipment, someone may have incorrectly changed them during attempted repairs. A wrong-value part is quite likely in new construction, such as a home-brew or kit project.

26.5.1 Voltage Levels

Check the circuit voltages. If the voltage levels are printed on the schematic, this is easy. If not, analyze the circuit and make some calculations to see what the circuit voltages should be. Remember, however, that the printed or calculated voltages are nominal; measured voltages may vary from the calculations.

When making measurements, remember the following points:

- Make measurements at device leads, not at circuit-board traces or socket lugs.
- Use small test probes to prevent accidental shorts.
- Never connect or disconnect power to solid-state circuits with the switch on.
- Remember that voltmeters, particularly older analog meters, may load down a high-impedance circuit and change the voltage, as will ×1 and low-impedance scope probes.

Voltages may give you a clue to what is wrong with the circuit. If not, check the active device. If you can check the active device in the circuit, do so. If not, remove it and test it, or substitute a known good device. After connections, most circuit failures are caused directly or indirectly by a bad active device. The experienced troubleshooter usually tests or substitutes these first. Analyze the other components and determine the best way to test each as described earlier.

There are two voltage levels in most analog circuits (V+ and ground, for example). Most component failures (opens and shorts) will shift dc voltages near one of these levels. Typical failures that show up as incorrect dc voltages include open coupling transformers; shorted capacitors; open, shorted or overheated resistors; and open or shorted semiconductors.

Digital logic circuits require that signals be within specific voltage ranges to be treated as a valid logic-low or logic-high value.

26.5.2 Noise

A slight hiss is normal in all electronic circuits. This noise is produced whenever current flows through a conductor that is warmer than absolute zero. Noise is compounded and amplified by succeeding stages. Repair is necessary only when noise threatens to obscure normally clear signals.

Semiconductors can produce hiss in two ways. The first is normal — an even white noise that is much quieter than the desired signal. Faulty devices frequently produce excessive noise. The noise from a faulty device is often erratic, with pops and crashes that are sometimes louder than the desired signal. In an analog circuit, the end result of noise is usually sound. In a control or digital circuit, noise causes erratic operation: unexpected switching and so on.

Noise problems usually increase with temperature, so localized heat may help you find the source. Noise from any component may be sensitive to mechanical vibration. Tapping various components with an insulated screwdriver may quickly isolate a bad part. Noise can also be traced with an oscilloscope or signal tracer.

Nearly any component or connection can be a source of noise. Defective components are the most common cause of crackling noises. Defective connections are a common cause of loud, popping noises.

Check connections at cables, sockets and switches. Look for dirty variable capacitor wipers and potentiometers. An arcing mica trimmer capacitor can create static crashes in received or transmitted audio. Test it by installing a series 0.01 µF capacitor. If the noise disappears, replace the trimmer.

Potentiometers are particularly prone to noise problems when used in dc circuits. Clean them with a small amount of spray contact cleaner and rotate the shaft several times.

Rotary switches may be tested by jumpering the contacts with a clip lead. Loose contacts may sometimes be repaired, either by cleaning, carefully rebending the switch contacts or gluing loose switch parts to the switch deck. Operate variable components through their range while observing the noise level at the circuit output.

26.5.3 Oscillations

Oscillations occur whenever there is sufficient positive feedback in a circuit that has gain. (This can even include digital devices.) Oscillation may occur at any frequency from a low-frequency "putt-putt" (often called *motorboating*) well up into the RF region.

Unwanted oscillations are usually the result of changes in the active device (increased junction or interelectrode capacitance), failure of an oscillation suppressing component (open decoupling or bypass capacitors or neutralizing components) or new feedback paths (improper lead dress or dirt on the chassis or components). It can also be caused by improper design, especially in home-brew circuits. A shift in bias or drive levels may aggravate oscillation problems.

Oscillations that occur in audio stages do not change as the radio is tuned because the operating frequency — and therefore the component impedances — do not change. RF and IF oscillations, however, usually vary in amplitude as operating frequency is changed.

Oscillation stops when the positive feedback is removed. Locating and replacing a defective (or missing) bypass capacitor may effect an improvement. The defective oscillating stage can be found most reliably with an oscilloscope.

26.5.4 Amplitude Distortion

Amplitude distortion is the product of nonlinear operation. The resultant waveform contains not only the input signal but new signals at other frequencies as well. All of the frequencies combine to produce the distorted waveform. Distortion in a transmitter gives rise to splatter, harmonics and interference.

Figure 26.15 shows some typical cases of distortion. Clipping (also called flat-topping) is the consequence of excessive drive, a change in bias, or insufficient supply voltage to the circuit. The corners on the waveform show that harmonics are present. (A square wave contains the fundamental and all odd harmonics.) If this were a transmitter circuit, these odd harmonics would be heard well away from the operating frequency, possibly outside of amateur bands.

Harmonic distortion produces radiation at frequencies far removed from the fundamental; it is a major cause of electromagnetic interference (EMI). Harmonics are generated in nearly every amplifier. When they occur in a transmitter, they are usually caused by insufficient transmitter filtering (either by design,

Controlling Key Clicks

Key clicks are a special type of amplitude distortion caused by fast rising and falling edges of the output waveform or from abrupt disturbances in an otherwise smooth waveform. See the **Transmitting** chapter for more information about controlling key clicks. Most modern radios offer user configuration options to adjust keying rise and fall times. Older radios may require modification of a timing circuit that controls rise and fall time. Be a good neighbor to other operators and eliminate key clicks on your signal!

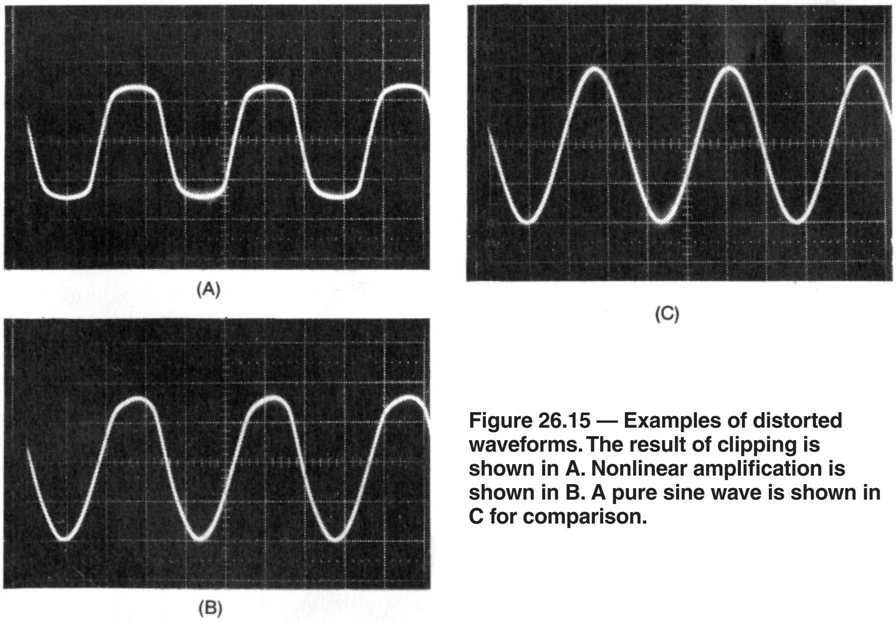

Figure 26.15 — Examples of distorted waveforms. The result of clipping is shown in A. Nonlinear amplification is shown in B. A pure sine wave is shown in C for comparison.

or because of filter component failure).

Anything that changes the proper bias of an amplifier can cause distortion. This includes failures in the bias components, leaky transistors or vacuum tubes with interelectrode shorts. In a receiver, these conditions may mimic AGC trouble. Improper bias of an analog circuit often results from a resistor that changed value or a leaky or shorted capacitor. RF feedback can also produce distortion by disturbing bias levels. Distortion is also caused by circuit imbalance in Class AB or B amplifiers.

Oscillations in an IF amplifier may produce distortion. They cause constant, full AGC action, or generate spurious signals that mix with the desired signal. IF oscillations are usually evident on the S meter, which will show a strong signal even with the antenna disconnected.

26.5.5 Frequency Response

Every circuit, even a broadband circuit, has a desired frequency response. Audio amplifiers used in amateur SSB circuits, for example, typically are designed for signals between 300 and 3000 Hz, more or less. A tuned IF amplifier may have a bandwidth of 50 to 100 kHz around the stage's center frequency. Any change in the circuit's frequency response can alter its effect on the signals on which it operates.

Frequency response changes are almost always a consequence of a capacitor or inductor changing value. The easiest way to check frequency response is to either inject a signal into the circuit and measure the output at several frequencies or use a spectrum analyzer or a signal generator's sweep function. In LC networks, it is relatively simple to lift one lead of the component and use a component checker to determine the value.

26.5.6 Distortion Measurement

A distortion meter is used to measure distortion of AF signals. A spectrum analyzer is the best piece of test gear to measure distortion of RF signals. If a distortion meter is not available, an estimation of AF distortion can sometimes be made with a function generator and an oscilloscope. Inject a square wave signal into the circuit with a fundamental frequency roughly in the middle of the expected frequency response.

Compare the input square wave to the output signal with an oscilloscope. **Figure 26.16** shows several effects on the square wave that are related to frequency response. These provide clues to what components or devices may be causing the problem. Severe distortion indicates some other problem besides frequency response changes.

26.5.7 Alignment

Alignment — the tuning or calibration of frequency sensitive circuits — is rarely the cause of an electronics problem with receiving or transmitting equipment, particularly modern equipment. Alignment does not shift suddenly and should be a last resort for treating sensitivity or frequency response problems. Do not attempt to adjust alignment without the proper equipment and alignment procedures. The process often requires steps to be performed exactly and in a specific order. Equipment misaligned in this way usually must be professionally repaired as a consequence.

26.5.8 Contamination

Contamination is another common service problem. Soda or coffee spilled into a piece

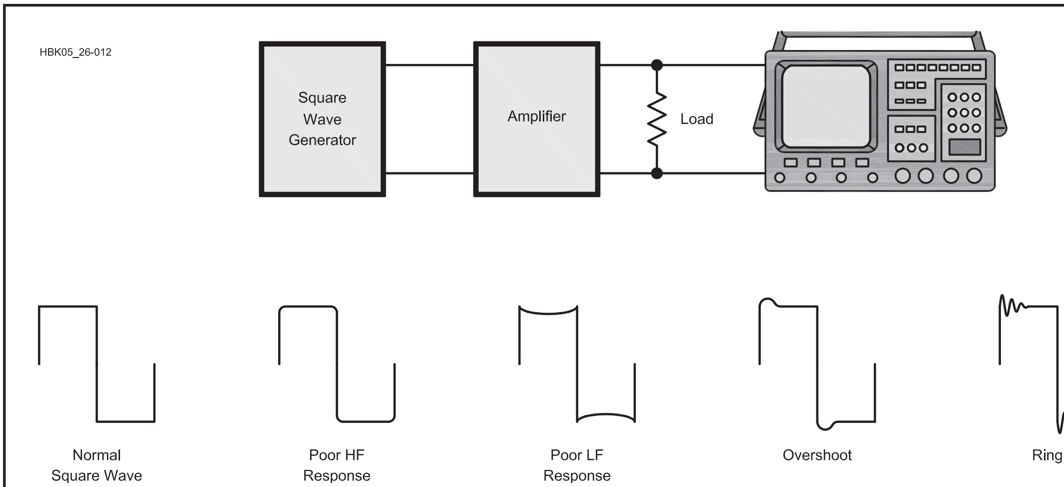

Figure 26.16 — Square-wave distortion from different causes.

of electronics is an extreme example (but one that does actually happen).

Conductive contaminants range from water to metal filings. Most can be removed by a thorough cleaning. Any of the residue-free cleaners can be used, but remember that the cleaner may also be conductive. Do not apply power to the circuit until the area is completely dry.

Keep cleaners away from variable-capacitor plates, transformers, and parts that may be harmed by the chemical. The most common conductive contaminant is solder, either from a printed circuit board solder bridge or a loose piece of solder deciding to surface at the most inconvenient time.

High-voltage circuits attract significant amounts of dust, described in the section on high-power amplifier maintenance later in this chapter. Cooling fans and ventilation holes also allow dust to accumulate, creating conductive paths between components. If not removed, the conductive paths gradually become lower in resistance until they begin to affect equipment performance. Vacuuming or blowing out the equipment is usually sufficient to clear away dust, although a carbon track may require a more thorough cleaning.

26.5.9 Solder Bridges

In a typical PC-board solder bridge, the solder that is used to solder one component has formed a short circuit to another PC-board trace or component. Unfortunately, they are common in both new construction and repair work. Look carefully for them after you have completed any soldering, especially on a PC-board. It is even possible that a solder bridge may exist in equipment you have owned for a long time, unnoticed until it suddenly became a short circuit.

Related items are loose solder blobs, loose hardware or small pieces of component leads that can show up in the most awkward and troublesome places.

26.5.10 Arcing

Arcing is a serious sign of trouble. It may also be a real fire hazard. Arc sites are usually easy to find because an arc that generates visible light or noticeable sound also pits and discolors conductors.

Arcing is caused by component failure, dampness, dirt or lead dress. If the dampness is temporary, dry the area thoroughly and resume operation. Dirt may be cleaned from the chassis with a residue-free cleaner. Arrange leads so high-voltage conductors are isolated. Keep them away from sharp corners and screw points.

Arcing occurs in capacitors when the working voltage is exceeded. Air-dielectric variable capacitors can sustain occasional arcs without damage, but arcing indicates operation beyond circuit limits. Antenna tuners working beyond their ability may suffer from arcing. A failure or high SWR in an antenna circuit may also cause transmitter arcing. Prolonged, repeated, or high-power arcing can cause pits or deposits on capacitor plates that reduce capacitor voltage rating and lead to more arcing.

26.5.11 Digital Circuitry

Although every aspect of digital circuit operation may be resolved to a simple 1 or 0, or tristate (open circuit), the symptoms of failure are far more complicated. The most common problems are false triggers or counts, digital inputs that do not respond to valid logic signals, and digital outputs stuck at ground or the supply voltage.

In most working digital circuitry the signals are constantly changing between low and high states, often at RF rates. Low-frequency or dc meters should not be used to check digital signal lines. A logic probe is often helpful in determining signal state and whether it is active or not. An oscilloscope or logic analyzer is usually needed to troubleshoot digital circuitry beyond simple go/no-go testing.

If you want to use an oscilloscope to give an accurate representation of digital signals, the scope bandwidth must be at least several times the highest clock frequency in the circuit in order to reproduce the fast rise and fall times of digital signals. Lower-bandwidth scopes can be useful in determining whether a signal is present or active, but they often miss short glitch signals (very fast transients) that are often associated with digital circuit malfunction.

LOGIC LEVELS

Begin by checking for the correct voltages at the pins of each IC. The correct logic voltages are specified in the device's datasheet, which will also identify the power pins (V_{cc} and ground). The voltages on the other pins should be a logic high, a logic low, or tristate (more on this later).

Most digital circuit failures are caused by a failed logic IC. IC failures are almost always catastrophic. It is unlikely that an AND gate will suddenly start functioning like an OR gate. It is more likely that the gate will have a signal at its input, and no signal at the output. In a failed device, the output pin will have a steady voltage. In some cases, the voltage is steady because one of the input signals is missing. Look carefully at what is going into a digital IC to determine what should be coming out. Manufacturers' datasheets describe the proper functioning of most digital devices.

TRISTATE DEVICES

Many digital devices are designed with a third logic state, commonly called tristate. In this state, the output of the device acts as an open circuit so that several device outputs can be connected to a common bus. The outputs that are active at any given time are selected by software or hardware control signals. A computer's data and address busses are good examples of this. If any device output connected to the bus fails by becoming locked or stuck in a 0 or 1 logic state, the entire bus becomes nonfunctional. Tristate devices can also be locked on by a failure of the signal that controls the tristate output status.

SIMPLE GATE TESTS

Most discrete logic ICs (collections of individual gates or other logic functions) are easily tested by in-circuit inspection of the input and output signals. The device's truth table or other behavior description specifies what the proper input and output signals should be. Testing of more complicated ICs requires the use of a logic analyzer, multi-trace scope or a dedicated IC tester. If a simple logic IC is found to be questionable, it is usually easiest to simply substitute a new device for it.

CLOCK SIGNALS

In clocked circuits, check to see if the clock signal is active. If the signal is found at the clock chip, trace it to each of the other ICs to be sure that the clock system is intact. Clock frequencies are rarely wrong but clock signals derived from a master clock can be missing or erratic if the circuitry that creates them is defective.

RF INTERFERENCE

If digital circuitry interferes with other nearby equipment, it may be radiating spurious signals. These signals can interfere with your amateur radio operation or other services. Computer networking and microprocessor-controlled consumer equipment generates a significant amount of noise due to RF being radiated from cables and unshielded equipment.

Digital circuitry can also be subject to interference from strong RF fields. Erratic operation or a complete lock-up is often the result. Begin by removing the suspect equipment from RF fields. If the symptoms stop when there is no RF energy present, apply common-mode chokes as described in the **RF Interference** chapter..

The ARRL RFI Book has a chapter on computer and digital interference to and from digital devices and circuits. The subject is also covered in the **RF Interference** chapter of this book.

26.5.12 Replacing Parts

If you have located a defective component within a stage, you need to replace it. When replacing socket mounted components, be sure to align the replacement part correctly. Make sure that the pins of the device are properly inserted into the socket. See the **Construction Techniques** chapter for guidance on working with SMT components.

Some special tools can make it easier to remove soldered parts. A chisel-shaped soldering tip helps pry leads from printed-circuit boards or terminals. A desoldering iron or bulb forms a suction to remove excess solder, making it easier to remove the component. Spring-loaded desoldering pumps are more convenient than bulbs. Desoldering wick draws solder away from a joint when pressed against the joint with a hot soldering iron.

Removing soldered ICs is a lot simpler if you simply clip its leads next to the IC body using fine-point wire cutters, although it does destroy the IC. Then melt the solder and lift out the pin with tweezers or the wire cutter. Use the desoldering pumps or wick to remove the solder. This works well for both through-hole and SMT components.

26.6 After the Repairs

Once you have completed your troubleshooting and repairs, it is time to put the equipment back together. Take a little extra time to make sure you have done everything correctly.

26.6.1 All Units

Give the entire unit a complete visual inspection. Look for any loose ends left over from your troubleshooting procedures — you may have left a few components temporarily soldered in place, forgotten to reattach a wire or cable, or overlooked some other repair error. Look for cold solder joints and signs of damage incurred during the repair. Double-check the position, leads and polarity of components that were removed or replaced.

Make sure that all ICs and connectors are properly oriented and inserted in their sockets. Test fuse continuity with an ohmmeter and verify that the current rating matches the circuit specification.

Look at the position of all of the wires and components. Make sure that wires and cables will be clear of hot components, screw points and other sharp edges. Make certain that the wires and components will not be in the way and pinched or crimped when covers are installed and the unit is put back together.

Separate the leads that carry dc, RF, input and output as much as possible. Plug-in circuit boards should be firmly seated with screws tightened and lock washers installed if so specified. Shields and ground straps should be installed just as they were on the original.

26.6.2 Transmitter Checkout

Since the signal produced by an HF transmitter can be heard the world over, a thorough check is necessary after any service has been performed. Do not exceed the transmitter duty cycle while testing. Limit transmissions to 10 to 20 seconds unless otherwise specified by the owner's manual.

1. Set all controls as specified in the operation manual, or at midscale.
2. Connect a dummy load and a power meter to the transmitter output.
3. Set the drive or carrier control for low output.
4. Switch the power on.
5. Transmit and quickly set the final-amplifier bias to specifications if necessary
6. For vacuum tube final amplifiers, slowly tune the output network through resonance. The current dip should be smooth and repeatable. It should occur simultaneously with the maximum power output. Any sudden jumps or wiggles of the current meter indicate that the amplifier is unstable. Adjust the neutralization circuit (according to the manufacturer's instructions) if one is present, or check for oscillation. An amplifier usually requires neutralization whenever active devices, components or lead dress (that affect the output/input capacitance) are changed.
7. Check to see that the output power is consistent with the amplifier class used in the PA (efficiency should be about 25% for Class A, 50 to 60% for Class AB or B, and 70 to 75% for Class C). Problems are indicated by the efficiency being significantly low.
8. Repeat steps 4 through 6 for each band of operation from lowest to highest frequency.
9. Check the carrier balance (in SSB transmitters only) and adjust for minimum power output with maximum RF drive and no microphone gain.
10. Adjust the VOX controls.
11. Measure the passband and distortion levels if equipment (wideband scope or spectrum analyzer) is available.

26.6.3 Other Repaired Circuits

After the preliminary checks, set the circuit controls per the manufacturer's specifications (or to midrange if specifications are not available) and switch the power on. Watch and smell for smoke, and listen for odd sounds such as arcing or hum. Operate the circuit for a few minutes, consistent with allowable duty cycle. Verify that all operating controls function properly.

Check for intermittent connections by subjecting the circuit to heat, cold and slight flexure. Also, tap or jiggle the chassis lightly with an alignment tool or other insulator.

If the equipment is meant for mobile or portable service, operate it through an appropriate temperature range. Many mobile radios do not work on cold mornings, or on hot afternoons, because a temperature-dependent intermittent was not found during repairs.

26.6.4 Close It Up

After you are convinced that you have repaired the circuit properly, put it all back together. If you followed the advice in this book, you have all the screws and assorted doodads in a secure container. Look at the notes you took while taking it apart; put it back together in the reverse order. Don't forget to reconnect all internal connections, such as ac power, speaker or antenna leads.

Once the case is closed, and all appears well, don't neglect the final, important step — make sure it still works. Many an experienced technician has forgotten this important step, only to discover that some minor error, such as a forgotten antenna cable, has left the equipment nonfunctional.

26.7 Professional Repairs

Repairs that deal with very complex and temperamental circuits, or that require sophisticated test equipment, should be passed on to a professional. Factory authorized service personnel have a lot of experience. What seems like a servicing nightmare to you is old hat to them. There is no one better qualified to service your equipment than factory personnel.

If the manufacturer is no longer in business, check with your local dealer or look through amateur radio magazines and websites. You can usually find one or more companies or repair services that handle all makes and models. Your local club or a user's group may also be able to make a recommendation.

If you are going to ship your equipment somewhere for repair, notify the repair center first. Get authorization for shipping and an identification name or number for the package.

26.7.1 Packing Equipment

You can always blame shipping damage on the shipper, but it is a lot easier for all concerned if you package your equipment properly for shipping in the first place.

• Take photos of the equipment before packing it to document its condition before shipping. Additional photos during the packing steps might also be useful to show that you took the proper care in packing the equipment.

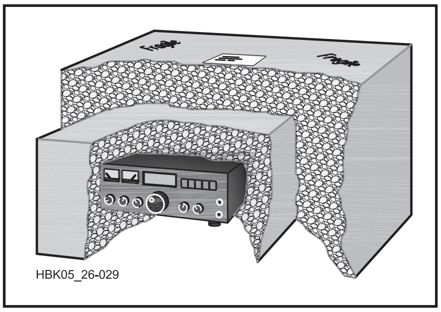

Figure 26.17 — Ship equipment packed securely in a box within a box.

• Firmly secure all heavy components, either by tying them down or blocking them off with shipping foam.

• Large transformers, such as for RF power amplifiers, should probably be removed and shipped separately.

• Large vacuum tubes should be wrapped in packing material or shipped separately.

• Make sure that all circuit boards and parts are firmly attached.

If you have the original shipping container, including all of the packing material, you should use that if the repair facility approves doing so. Otherwise use a box within a box for shipping (see **Figure 26.17**). Place the equipment and some packing material inside a box and seal it with tape. Place that box inside another that is at least six inches larger in each dimension.

Don't forget to enclose a statement of the trouble, a short history of operation and any test results that may help the service technician. Include a good description of the things you have tried. Be honest! At current repair rates you want to tell the technician everything to help ensure an efficient repair. Place the necessary correspondence, statement of symptoms, and your contact information in a mailing envelope and place it just inside the top covers of the outer box, or tape it to the top of the inner box.

Fill any remaining gaps with packing material and seal, address and mark the outer box. Choose a good freight carrier and insure the package. If available, get a tracking number for the package so you can tell when it was delivered.

Even if you tried to fix it yourself but ended up sending it back to the factory, you can feel good about your experience. You learned a lot by trying, and you have sent it back knowing that it really did require the services of a pro. Each time you troubleshoot and repair a piece of electronic circuitry, you learn something new. The downside is that you may develop a reputation as a real electronics whiz. You may find yourself spending a lot of time at club meetings offering advice, or getting invited over to a lot of shacks for a late-evening pizza snack. There are worse fates.

26.8 Typical Symptoms and Faults

26.8.1 Power Supplies

Many equipment failures are caused by power supply trouble. Fortunately, most power supply problems are easy to find and repair. This section focuses on the common linear power supply. Some notes are also made about switchmode supplies. Both types are discussed in detail in the **Power Sources** chapter, including projects with typical schematics.

LINEAR POWER SUPPLIES

The block diagram for a linear power supply is shown in **Figure 26.18.** First, use a voltmeter to measure output. Complete loss of output voltage is usually caused by an open circuit. (A short circuit draws excessive current that opens the fuse, thus becoming an open circuit.) If output voltage appears normal, apply a small load (1/10th supply capacity or smaller) and test output voltage again. If the small load causes voltage to drop, there is generally a problem in the regulator circuitry, often the pass transistors.

If the ac input circuit fuse is blown, that is usually caused by a shorted diode in the filter block, a failure of the output protection circuitry, or a short circuit in the device being powered by the supply. More rarely, one of the filter capacitors can short. If the fuse has opened, turn off the power, replace the fuse, and measure the load-circuit's dc resistance. The measured resistance should be consistent with the power-supply ratings. A short or open load circuit indicates a problem.

If the measured resistance is too low, troubleshoot the load circuit. (Nominal circuit resistances are included in some equipment manuals.) If the load circuit resistance is normal, suspect a defective regulator IC or a problem in the rest of the unit.

IC regulators can oscillate, sometimes causing failure. The small-value capacitors on the input, output or adjustment pins of the regulator prevent oscillations. Check or replace these capacitors whenever a regulator has failed.

AC ripple (120 Hz buzz) is usually caused by low-value filter capacitors in the power

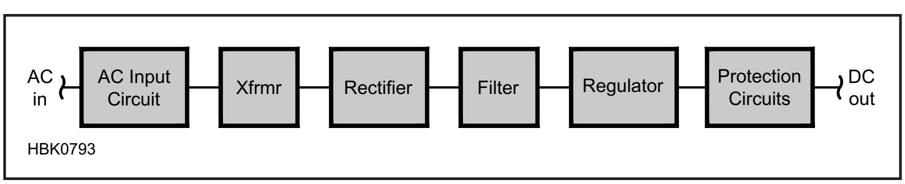

Figure 26.18 — Block diagram of a typical linear power supply.

supply. Ripple can also become excessive due to overload or regulation problems. Look for a defective filter capacitor (usually open or low-value), defective regulator, or shorted filter choke if chokes are used (not common in modern equipment). In older equipment, the defective filter capacitor will often have visible leaking electrolyte: look for corrosion residue at the capacitor leads. In new construction projects make sure RF energy is not getting into the power supply.

Here's an easy filter capacitor test: Temporarily connect a replacement capacitor (about the same value and working voltage) across the suspect capacitor. If the hum goes away, replace the bad component permanently.

Once the faulty component is found, inspect the surrounding circuit and consider what may have caused the problem. Sometimes one bad component can cause another to fail. For example, a shorted filter capacitor increases current flow and burns out a rectifier diode. While the defective diode is easy to find, the capacitor may show no visible damage.

If none of these initial checks find the problem, here are the usual systematic steps to locate the part of the supply with a problem:

• Check the input ac through switches and fuses to the transformer primary.

• Verify that the transformer secondary outputs ac of the right voltage. Disconnect the output leads, if necessary.

• Check the rectifiers for shorted diodes. Disconnect the rectifier output and test for output with a resistor load.

• Reconnect the filter and disconnect the regulator. Verify that the right dc voltage is present at the filter output.

• Reconnect the regulator and in the regulator IC or circuit test every pin or signal, especially enable/disable/soft-start and the voltage reference.

• Disconnect any output protective circuitry and verify that the pass transistors are working with a resistor load.

• Reconnect and test the output protective circuitry.

SWITCHMODE POWER SUPPLIES

Switchmode or switching power supplies are quite different from conventional supplies. In a switcher, the regulator circuit is based on a switching transistor and energy storage inductor instead of a pass transistor to change power from one dc level to another that can be higher or lower than the input voltage. Switching frequencies range from 20-120 kHz for most supplies and up to the MHz range for miniature dc-dc converter modules.

Switchmode supplies operating from the ac line have similar input circuits to linear supplies. The transformer that supplies isolation is then located in the low-voltage, high frequency section.

Apply the same input and output block-level tests as for linear supplies. The regulator circuitry in a swichmode supply is more complex than for a linear supply, but it usually is implemented in a single regulator IC. Failure of the regulator IC, transistor switch, or feedback path usually results in a completely dead supply. While active device failure is still the number one suspect, it pays to carefully test all components in the regulator subsystem.

HIGH-VOLTAGE POWER SUPPLIES

Obviously, testing HV supplies requires extreme caution. See the safety discussion at the beginning of this chapter, the **Safety** chapter of this book, and the discussion of HV supplies in the **Power Sources** chapter. If you do not feel comfortable working on HV supplies, then don't. Ask for help or hire a professional repair service to do the job.

Most HV supplies used in amateur equipment are linear supplies with the same general structure as low voltage supplies. A typical supply is presented as a project in the **Power Sources** chapter and the same basic steps can be applied — just with a lot more caution.

Components in a string, such as rectifiers or filter capacitors, should all be tested if any are determined to have failed. This is particularly true for capacitors, which can fail in sequence if one capacitor in the string shorts. Voltage equalizing resistors are not required for rectifier diodes available today, such as the 1N5408. Consider replacing older rectifier strings with new rectifiers as a preventive maintenance step.

Interlocks rarely fail, but verify that they are functioning properly before assuming they are in good working order.

26.8.2 Amplifier Circuits

Amplifiers are the most common circuits in electronics. The output of an ideal amplifier would match the input signal in every respect except magnitude: no distortion or noise would be added. Real amplifiers always add noise and distortion. Typical discrete and op-amp amplifier circuits are described in the **Analog Basics** chapter.

AMPLIFIER GAIN

Amplifier failure usually results in a loss of gain or excessive distortion at the amplifier output. In either case, check external connections first. Is there power to the stage? Has the fuse opened? Check the speaker and leads in audio output stages, the microphone and push-to-talk (PTT) line in transmitter audio sections. Excess voltage, excess current or thermal runaway can cause sudden failure of semiconductors. The failure may appear as either a short circuit or open circuit of one or more PN junctions.

Thermal runaway occurs most often in bipolar transistor circuits. If degenerative feedback (the emitter resistor reduces base-emitter voltage as conduction increases) is insufficient, thermal runaway will allow excessive current flow and device failure. Check transistors by substitution, if possible. If not, voltage checks as described below usually turn up the problem.

Faulty coupling components can reduce amplifier output. Look for component failures that would increase series impedance, or decrease shunt impedance, in the coupling network. Coupling faults can be located by signal tracing or parts substitution. Other passive component defects reduce amplifier output by shifting bias or causing active-device failure. These failures are evident when the dc operating voltages are measured.

If an amplifier is used inside a feedback loop, faults in the feedback loop can force a transistor into cutoff or saturation, or force an op amp's output to either power supply rail. In a receiver, the AGC subsystem is such a feedback loop. Open the AGC line to the device and substitute a variable voltage for the AGC signal. If amplifier action varies with voltage, suspect the AGC-circuit components; otherwise, suspect the amplifier.

In an operating amplifier, check carefully for oscillations or noise. Oscillations are most likely to start with maximum gain and the amplifier input shorted. Any noise that is due to 60 Hz sources can be heard, or seen with an oscilloscope triggered by the ac line.

Unwanted amplifier RF oscillations should be cured with changes of lead dress or circuit components. Separate input leads from output leads; use coaxial cable to carry RF between stages; neutralize inter-element or junction capacitance. Ferrite beads on the control element of the active device often stop unwanted oscillations.

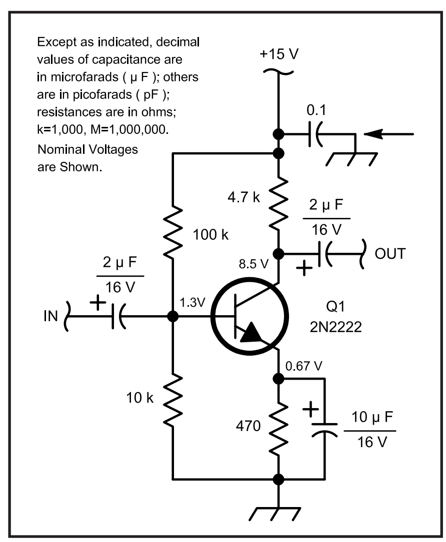

Figure 26.19 — The decoupling capacitor in this circuit is designated with an arrow.

Low-frequency oscillations (motorboating) indicate poor stage isolation or inadequate power supply filtering. Try a better lead-dress arrangement and/or check the capacitance of the decoupling network (see **Figure 26.19**). Use larger capacitors at the power supply leads; increase the number of capacitors or use separate decoupling capacitors at each stage. Coupling capacitors that are too low in value can also cause poor low-frequency response. Poor response to high frequencies is usually caused by circuit design.

COMMON-EMITTER AMPLIFIER

The common-emitter circuit (or common-source using an FET) is the most widely used configuration. It can be used as an amplifier or as a switch. Both are analyzed here as an example of how to troubleshoot transistor amplifier circuits. Other types of circuit can be analyzed similarly

Figure 26.20 is a schematic of a common-emitter transistor amplifier. The emitter, base and collector leads are labeled e, b and c, respectively. Important dc voltages are measured at the emitter (V_e), base (V_b) and collector (V_c) leads. V+ is the supply voltage.

First, analyze the voltages and signal levels in this circuit. The junction drop is the potential measured across a semiconductor junction that is conducting. It is typically 0.6 V for silicon and 0.2 V for germanium transistors.

This is a Class-A linear circuit. In Class-A circuits, the transistor is always conducting some current. R1 and R2 form a voltage divider that supplies dc bias (V_b) for the transistor. Normally, V_e is equal to V_b less the emitter-base junction drop. R4 provides degenerative dc bias, while C3 provides a low-impedance path for the signal. From this information, normal operating voltages can be estimated.

The bias and voltages will be set up so that the transistor collector voltage, V_c, is somewhere between V+ and ground potential. A good rule of thumb is that V_c should be about one-half of V+, although this can vary quite a bit, depending on component tolerances. The emitter voltage is usually a small percentage of V_c, say about 10%.

Any circuit failure that changes collector current, I_c, (ranging from a shorted transistor to a failure in the bias circuit) changes V_c and V_e as well. An increase of I_c lowers V_c and raises V_e. If the transistor shorts from collector to emitter, V_c drops to about 1.2 V, as determined by the voltage divider formed by R3 and R4.

You would see nearly the same effect if the transistor were biased into saturation by collector-to-base leakage, a reduction in R1's value or an increase in R2's value. All of these circuit failures have the same effect. In some cases, a short in C1 or C2 could cause the same symptoms.

To properly diagnose the specific cause of low V_c, consider and test all of these parts. It is even more complex; an increase in R3's value would also decrease V_c. There would be one valuable clue, however: if R3 increased in value, I_c would not increase; V_e would also be low.

Anything that decreases I_c increases V_c. If the transistor failed open, R1 increased in value, R2 were shorted to ground or R4 opened, then V_c would be high.

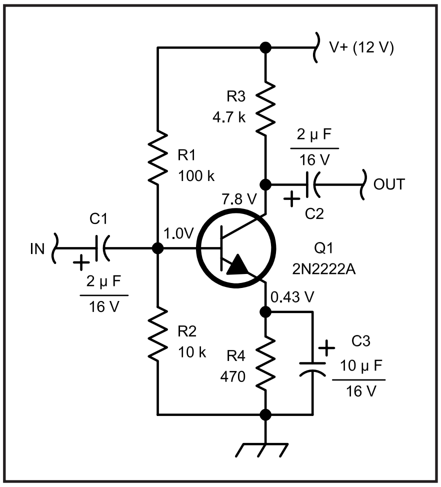

Figure 26.20 — A typical common-emitter audio amplifier.

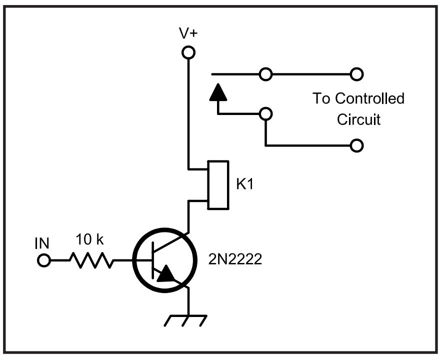

Figure 26.21 — A typical common-emitter switch or driver.

COMMON-EMITTER SWITCH

A common-emitter transistor switching circuit is shown in **Figure 26.21**. This circuit functions differently from the circuit shown in Figure 26.20. A linear amplifier is designed so that the output signal is a faithful reproduction of the input signal. Its input and output may have any value from V+ to ground.

The switching circuit of Figure 26.21, however, is similar to a digital circuit. The active device is either on or off, 1 or 0, just like digital logic. Its input signal level should either be 0 V or positive enough to switch the transistor on fully (saturate). Its output state should be either full off (with no current flowing through the relay), or full on (with the relay energized). A voltmeter placed on the collector will show either approximately +12 V or 0 V, depending on the input.

Understanding this difference in operation is crucial to troubleshooting the two circuits. If V_c were +12 V in the circuit in Figure 26.20, it would indicate a circuit failure. A V_c of +12 V in the switching circuit is normal when V_b is 0 V. (If V_b measured 0.8 V or higher, V_c should be low and the relay energized.)

DC-COUPLED AMPLIFIERS

In dc-coupled amplifiers, the transistors are directly connected together without coupling capacitors. They comprise a unique troubleshooting case. Most often, when one device fails, it destroys one or more other semiconductors in the circuit. If you don't find all of the bad parts, the remaining defective parts can cause the installed replacements to fail immediately. To reliably troubleshoot a dc coupled circuit, you must test every semiconductor in the circuit and replace them all at once.

26.8.3 Oscillators

In many circuits, a failure of the oscillator will result in complete circuit failure. A transmitter will not transmit, and a superheterodyne receiver will not receive if you have an internal oscillator failure. (These symptoms do not always mean oscillator failure, however.)

Whenever there is weakening or complete loss of signal from a radio, check oscillator operation and frequency. There are several methods:

- Use a receiver with a coaxial probe to listen for the oscillator signal.
- A dip meter can be used to check oscillators by tuning to within ±15 kHz of the oscillator, coupling it to the circuit, and listening for a beat note in the dip-meter headphones.
- Look at the oscillator waveform on a scope. The operating frequency can't be determined with great accuracy, but you can see if the oscillator is working at all. Use a low capacitance (10×) probe for oscillator observations.

Many modern oscillators are phase-locked loops (PLLs). Read the **Oscillators and Synthesizers** chapter of this book in order to learn how PLLs operate.

To test for a failed LC oscillator, use a dip meter in the active mode. Set the dip meter to the oscillator frequency and couple it to the oscillator output circuit. If the oscillator is dead, the dip-meter signal will take its place and temporarily restore some semblance of normal operation.

STABILITY

Drift is caused by variations in the oscillator. Poor voltage regulation and heat are the most common culprits. Check regulation with a voltmeter (use one that is not affected by RF). Voltage regulators are usually part of the oscillator circuit. Check them by substitution.

Chirp is a form of rapid drift that is usually caused by excessive oscillator loading or poor power-supply regulation. The most common cause of chirp is poor design. If chirp appears suddenly in a working circuit, look for component or design defects in the oscillator or its buffer amplifiers. (For example, a shorted coupling capacitor increases loading drastically.) Also check for new feedback paths from changes in wiring or component placement (feedback defeats buffer action).

Frequency instability may also result from defects in feedback components. Too much feedback may produce spurious signals, while too little makes oscillator start-up unreliable.

Sudden frequency changes are frequently the result of physical variations. Loose components or connections are probable causes. Check for arcing or dirt on printed circuit boards, trimmers and variable capacitors, loose switch contacts, bad solder joints or loose connectors.

FREQUENCY ACCURACY

In manually tuned LC oscillators, tracking at the high-frequency end of the range is controlled by trimmer capacitors. A trimmer is a variable capacitor connected in parallel with the main tuning capacitor (see **Figure 26.22**). The trimmer represents a higher percentage of the total capacitance at the high end of the tuning range. It has relatively little effect on tuning characteristics at the low-frequency end of the range.

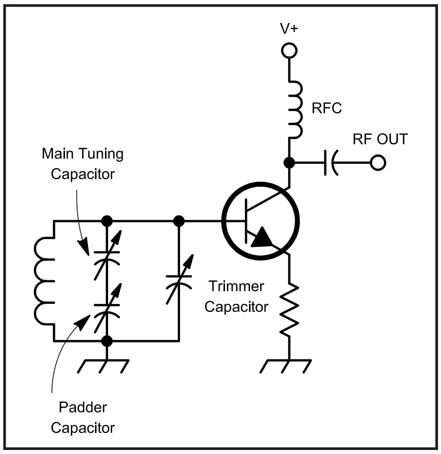

Figure 26.22 — A partial schematic of a simple oscillator showing the locations of the trimmer and padder capacitors.

Low-end range is adjusted by a series trimmer capacitor called a *padder*. A padder is a variable capacitor that is connected in series with the main tuning capacitor. Padder capacitance has a greater effect at the low-frequency end of the range. The padder capacitor is often eliminated to save money. In that case, the low-frequency range is set by adjusting the main tuning coil.

26.8.4 Transmit Amplifier Modules

Most VHF/UHF mobile radios and many small HF radios use commercial amplifier modules as the final amplifier instead of discrete transistors. These modules are quite reliable and can withstand various stresses such as disconnected antennas. However, replacement units are rarely available more than a few years after a particular radio model goes out of production. You may be able to find a damaged radio of the same model to scavenge for parts, but once the modules fail, you are usually out of luck. User's groups are often good sources of information about common failure modes of certain radios and possibly even sources of replacement parts.

The usual failure mode of an amplifier module is caused by thermal cycling that eventually leads to an internal connection developing a crack. The module becomes intermittent and then eventually fails completely. If you can open the module, you can sometimes identify and repair such a problem by soldering over the crack.

When reinstalling or replacing an amplifier module, be very careful to attach it to the heat sink as it was at the factory. Do not use excessive amounts of thermal compound or grease and make sure the mounting screws are secure. If you can find a datasheet for the module, check to see if there are recommendations for mounting screw torque and any other installation procedures. (See the **RF Power Amplifiers** chapter for guidelines on mounting power transistors.)

26.9 Radio Troubleshooting Hints

Tables 26.2, **26.3**, **26.4** and **26.5** list some common problems and possible cures for older radios that are likely to have developed problems with some later-model equivalents. These tables are not all-inclusive. They are a collection of hints and shortcuts that may save you some troubleshooting time. If you don't find your problem listed, continue with systematic troubleshooting.

Remember that many problems are caused by improper setting of a switch, a control, or a configuration menu item. Before beginning a troubleshooting session, be sure you've checked the operating manual for proper control settings and checked through the manual's troubleshooting guide. If possible, obtain a service manual with its detailed procedures, measurements, and schematics.

26.9.1 Receivers

A receiver can be diagnosed using any of the methods described earlier, but if there is not even a faint sound from the speaker, signal injection is not a good technique. If you lack troubleshooting experience, avoid following instinctive hunches. Begin with power supply tests and proceed to signal tracing.

SELECTIVITY

Failure of control or switching circuits that determine the signal path and filters can cause selectivity problems. In older equipment, tuned transformers or the components used in filter circuits may develop a shorted turn, capacitors can fail and alignment is required occasionally. Such defects are accompanied by a loss of sensitivity. Except in cases of catastrophic failure (where either the filter passes all signals, or none), it is difficult to spot a loss of selectivity. Bandwidth and insertion-loss measurements are necessary to judge filter performance.

SENSITIVITY

A gradual loss of sensitivity results from gradual degradation of an active device or long-term changes in component values. Sudden partial sensitivity changes are usually the result of a component failure, usually in the RF or IF stages. Excessive signal levels or

Table 26.2
Symptoms and Their Causes for All Electronic Equipment

Symptom	*Cause*
Power Supplies	
No output voltage	Open circuit (usually a fuse, pass transistor, or transformer winding)
Hum or ripple	Faulty regulator, capacitor or rectifier, low-frequency oscillation
Amplifiers	
Low gain	Transistor, coupling capacitors, emitter-bypass capacitor, AGC component
Noise	Transistors, coupling capacitors, resistors
Oscillations	Dirt on variable capacitor or chassis, shorted op-amp input
Oscillations, untuned (oscillations do not change with frequency)	Audio stages
Oscillations, tuned	RF, IF and mixer stages
Static-like crashes	Arcing trimmer capacitors, poor connections
Static in FM receiver	Faulty limiter stage, open capacitor in ratio detector, weak RF stage, weak incoming signal
Intermittent noise	All components and connections, band-switch contacts, potentiometers (especially in dc circuits), trimmer capacitors, poor antenna connections
Distortion (constant)	Oscillation, overload, faulty AGC, leaky transistor, open lead in tab-mount transistor, dirty potentiometer, leaky coupling capacitor, open bypass capacitors, imbalance in tuned FM detector, IF oscillations, RF feedback (cables)
Distortion (strong signals only)	Open AGC loop
Frequency change	Physical or electrical variations, dirty or faulty variable capacitor, broken switch, loose compartment parts, poor voltage regulation, oscillator tuning (trouble when switching bands)
No Signals	
All bands	Dead VFO or LO, PLL won't lock
One band only	Defective crystal, oscillator out of tune, band switch
No function control	Faulty switch or control, poor connection to front panel subassembly

Table 26.3
Receiver Problems

Symptom	*Cause*
Low sensitivity	Semiconductor degradation, circuit contamination, poor antenna connection
Signals and calibrator heard weakly	
(low S-meter readings)	RF chain
(strong S-meter readings)	AF chain, detector
No signals or calibrator heard, only hissing	RF oscillators
Distortion	
On strong signals only	AGC fault
AGC fault	Active device cut off or saturated
Difficult tuning	AGC fault
Inability to receive	Detector fault
AM weak and distorted	Poor detector, power, or ground connection
CW/SSB unintelligible	BFO off frequency or dead
FM distorted	Open detector diode

transients can damage input RF switching, amplifier, or mixing circuits. Complete and sudden loss of sensitivity is caused by an open circuit anywhere in the signal path or by a dead oscillator.

AGC

AGC failure usually causes distortion that affects only strong signals. All stages operate at maximum gain when the AGC influence is removed. An S meter can help diagnose AGC failure because it is operated by the AGC loop. If the S meter does not move at all or remains at full scale, the AGC system has a problem.

In DSP radios, the AGC function is often controlled by software which you cannot troubleshoot, but inputs to the software such as signal level detectors may be causing a problem instead.

In analog receivers, an open bypass capacitor in the AGC amplifier causes feedback through the loop. This often results in a receiver squeal (oscillation). Changes in the loop time constant affect tuning. If stations consistently blast, or are too weak for a brief time when first tuned in, the time constant is too fast. An excessively slow time constant makes tuning difficult, and stations fade after tuning. If the AGC is functioning but the timing seems wrong, check the large-value capacitors found in the AGC circuit — they usually set the AGC time constants. If the AGC is not functioning, check the AGC-detector circuit. There is often an AGC voltage that is used to control several stages. A failure in any one stage could affect the entire loop.

DETECTOR PROBLEMS

Detector trouble usually appears as complete loss or distortion of the received signal. AM, SSB and CW signals may be weak and unintelligible. FM signals will sound distorted. Look for an open circuit in the detector circuit. If tests of the detector parts indicate no trouble, look for a poor connection in the detector's power supply or ground connections. A BFO that is dead or off frequency prevents SSB and CW reception. In modern rigs, the BFO frequency is usually derived from the main VFO system.

26.9.2 Transmitters

Many potential transmitter faults are discussed in several different places in this chapter. There are, however, a few techniques used to ensure stable operation of RF amplifiers in transmitters that are not covered elsewhere.

RF final amplifiers often use parasitic chokes to prevent instability. Older parasitic chokes usually consist of a 51- to 100-Ω non-inductive resistor with a coil wound around the body and connected to the leads. It is used to prevent VHF and UHF oscillations in a vacuum-tube amplifier. The suppressor

Table 26.4
Transmitter Problems

Symptom	*Cause*
Key clicks	Keying filter, distortion in stages after keying, ALC overshoot or instability
Modulation Problems	
Loss of modulation	Broken cable (microphone, PTT, power), open circuit in audio chain, defective modulator
Distortion on transmit	Defective microphone, RF feedback, modulator imbalance, bypass capacitor, improper bias, excessive drive
Arcing	Dampness, dirt, improper lead dress
Low output	Incorrect control settings, improper carrier shift (CW signal outside of passband), audio oscillator failure, transistor or tube failure, SWR protection circuit
Antenna Problems	
Poor SWR	Damaged antenna element, matching network, feed line, balun failure (see below), resonant conductor near antenna, poor connection at antenna
Balun failure	Excessive SWR, weather or cold-flow damage in coil choke, broken wire or connection
RFI	Arcing or poor connections anywhere in antenna system or nearby conductors

Table 26.5
Transceiver Problems

Symptom	*Cause*
Inoperative S meter	Faulty TR switching or relay
PA noise in receiver	Faulty TR switching or relay
Excessive current on receive	Faulty TR switching or relay
Arcing in PA	Faulty TR switching or relay
Reduced signal strength on transmit and receive	IF failure
Poor VOX operation	VOX amplifiers
Poor VOX timing	Adjustment, component failure in VOX timing circuits or amplifiers
VOX consistently tripped by receiver audio	AntiVOX circuits or adjustment

is placed in the plate lead, close to the plate connection.

In recent years, problems with this style of suppressor have been discovered. See the **RF Power Amplifiers** chapter for information about suppressing parasitics. If parasitic suppressors are present in your transmitter, continue to use them as the exact layout and lead dress of the RF amplifier circuitry may require them to avoid oscillation. If they are not present, do not add them. When working on RF power amplifiers, take care to keep leads and components arranged just as they were when they left the factory.

Parasitic chokes often fail from excessive current flow. In these cases, the resistor is charred. Occasionally, physical shock or corrosion produces an open circuit in the coil. Test for continuity with an ohmmeter.

Transistor amplifiers are protected against parasitic oscillations by low-value resistors or ferrite beads in the base or collector leads. Resistors are used only at low power levels (about 0.5 W), and both methods work best when applied to the base lead. Negative feedback is used to prevent oscillations at lower frequencies. An open component in the feedback loop may cause low-frequency oscillation, especially in broadband amplifiers.

KEYING

The simplest form of modulation is on/off keying. Although it may seem that there cannot be much trouble with such an elementary form of modulation, two very important transmitter faults are the result of keying problems.

Key clicks are produced by fast rise and times of the keying waveform (see the previous sidebar, "Controlling Key Clicks"). Most transmitters include components in the keying circuitry to prevent clicks. When clicks are experienced, check the keying filter components first, then the succeeding stages. An improperly biased power amplifier, or a Class C amplifier that is not keyed, may produce key clicks even though the keying waveform earlier in the circuit is correct. Clicks caused by a linear amplifier may be a sign of low-frequency parasitic oscillations. If they occur in an amplifier, suspect insufficient power-supply decoupling. Check the power-supply filter capacitors and all bypass capacitors.

The other modulation problem associated with on/off keying is called backwave. Backwave is a condition in which the signal is heard, at a reduced level, even when the key is up. This occurs when the oscillator signal feeds through a keyed amplifier. This usually indicates a design flaw, although in some cases a component failure or improper keyed-stage neutralization may be to blame.

LOW OUTPUT POWER

Check the owner's manual to see if the condition is normal for some modes or bands, or if there is a menu item to set RF output power. Check the control settings. Solid-state transmitters require so little effort from the operator that control settings are seldom noticed. The CARRIER (or DRIVE) control may have been bumped. Remember to adjust tuned vacuum tube amplifiers after a significant change in operating frequency (usually 50 to 100 kHz). Most modern transmitters are also designed to reduce power if there is high (say 2:1) SWR. Check these obvious external problems before you tear apart your rig.

Power transistors may fail if the SWR protection circuit malfunctions. Such failures occur at the weak link in the amplifier chain: it is possible for the drivers to fail without damaging the finals. An open circuit in the reflected side of the sensing circuit leaves the transistors unprotected; a short shuts them down.

Low power output in a transmitter may also spring from a misadjusted carrier oscillator or a defective SWR protection circuit. If the carrier oscillator is set to a frequency well outside the transmitter passband, there may be no measurable output. Output power will increase steadily as the frequency is moved into the passband.

26.9.3 Transceivers

SWITCHING

Elaborate switching schemes are used in transceivers for signal control. Many transceiver malfunctions can be attributed to relay or switching problems. Suspect the switching controls when:

• The S meter is inoperative, but the unit otherwise functions. (This could also be a bad S meter or a consequence of a configuration menu item.)

• There is arcing in the tank circuit. (This could also be caused by a fault in the antenna system.)

• There is excessive broadband PA noise in the receiver.

Since transceiver circuits are shared, stage defects frequently affect both the transmit and receive modes, although the symptoms may change with mode. Oscillator problems usually affect both transmit and receive modes, but different oscillators, or frequencies, may be used for different emissions. Check the block diagram.

VOX

Voice operated transmit (VOX) controls are another potential trouble area. If there is difficulty in switching to transmit in the VOX mode, check the VOX-SENSITIVITY and ANTI-VOX control settings. Next, see if the PTT and manual (MOX) transmitter controls work. If the PTT and MOX controls function, examine the VOX control circuits. Test the switches, control lines and control voltage if the transmitter does not respond to other TR controls.

VOX SENSITIVITY and ANTI-VOX settings should also be checked if the transmitter switches on in response to received audio. Suspect the ANTI-VOX circuitry next. Unacceptable VOX timing results from a poor VOX-delay adjustment, or a bad resistor or capacitor in the timing circuit or VOX amplifiers.

26.9.4 Amplifiers

While this section focuses on vacuum-tube amplifiers using high-voltage (HV) supplies, it also applies to solid-state amplifiers that operate at lower voltages and generally have fewer points of failure. Amplifiers are simple, reliable pieces of equipment that respond well to basic care, regular maintenance, and common sense. A well-maintained amplifier will provide reliable service and maximum tube lifetime. (The complete version of a *QST* article on amplifier repair is included with the downloadable supplemental content.)

The key to finding the trouble with your amplifier (or any piece of sophisticated equipment) is to be careful and methodical, and to avoid jumping to false conclusions or making random tests. The manufacturer's customer service department will likely be helpful if you are considerate and have taken careful notes detailing the trouble symptoms and any differences from normal operation. There may be helpful guidelines on the manufacturer's web pages or from other internet resources. Sometimes there is more than one problem — they work together to act like one very strange puzzle. Just remember that most problems can be isolated by careful, step-by-step tests.

SAFETY FIRST

It is important to review good safety practices. (See the **Safe Practices** and **Power Sources** chapters for additional safety information.) Tube amplifiers use power supply voltages well in excess of 1 kV, and the RF output can be hundreds of volts, as well. Almost every voltage in a vacuum-tube amplifier can be lethal! Take care of yourself and use caution!

Power Control — Know and control the state of both ac line voltage and dc power supplies. Physically disconnect line cords and other power cables when you are not working on live equipment. Use a lockout on circuit breakers. Double-check visually and with a meter to be absolutely sure power has been removed.

Interlocks — Unless specifically instructed by the manufacturer's procedures to do so, never bypass an interlock. This is rarely required except in troubleshooting and should only be done when absolutely necessary. Interlocks are there to protect you.

The One-Hand Rule — Keep one hand in your pocket while making any measurements on live equipment. The hand in your pocket removes a path for current to flow through you. It's also a good idea to wear shoes with insulating soles and work on dry surfaces. Current can be lethal even at levels of a few mA — don't tempt the laws of physics.

Test Equipment Rating — Be sure your test equipment is adequately rated for the voltages and power levels encountered in amplifiers! This is particularly important in handheld equipment in which there is no metal enclosure connected to an ac safety ground. Excessive voltage can result in a *flashover* to the user from the internal electronics, probes, or test leads, resulting in electric shock. Know and respect this rating.

If you are using an external high voltage probe, make sure it is in good condition with no cracks in the body. The test lead insulation should be in good condition — flexible and with no cracks or wire exposed. If practical, do not make measurements while holding the probe or meter. Attach the probe with the voltage discharged and then turn the power on. Turn power off and discharge the voltage before touching the probe again. Treat high voltage with care and respect!

Patience — Repairing an amplifier isn't a race. Take your time. Don't work on equipment when you're tired or frustrated. Wait several minutes after turning the amplifier off to open the cabinet — capacitors can take several minutes to discharge through their bleeder resistors. On most amplifiers, the meter switch has a HV position — wait until it is at zero before opening the cabinet. Some amplifiers have a safety interlock that shorts the high voltage to ground — if the capacitor bank has not discharged, this can be quite spectacular — and destroy power supply components.

A Grounding Stick — Make the simple safety accessory shown in the High Voltage section of the **Power Sources** chapter and use it whenever you work on equipment in which hazardous voltages have been present. The ground wire should be heavy duty (#12 AWG or larger) due to the high peak currents (hundreds of amperes) present when discharging a capacitor or tripping a circuit breaker. When equipment is opened, touch the tip of the stick to every exposed component and connection that you might come in contact with. Assume nothing — accidental shorts and component failures can put voltage in places it shouldn't be.

The Buddy System and CPR — Use the buddy system when working around any equipment that has the potential for causing serious injury. The buddy needn't be a ham, just anyone who will be nearby in case of trouble. Your buddy should know how to remove power and administer basic first aid or CPR.

CLEANLINESS

The first rule in taking good care of an amplifier is cleanliness. Amplifiers need not be kept sparkling new, but their worst enemy is heat. Excess heat accelerates component aging and increases stress during operation.

Outside the amplifier, prevent dust and obstructions from blocking the paths by which heat is removed. This means keeping all ventilation holes free of dust, pet hair and insects. Fan intakes are particularly susceptible to inhaling all sorts of debris. Use a vacuum cleaner to clean the amplifier and surrounding areas. Keep liquids well away from the amplifier.

Keep papers or magazines off the amplifier — even if the cover is solid metal. Paper acts as an insulator and keeps heat from being radiated through the cover. Amplifier heat sinks must have free air circulation to be effective. There should be at least a couple of inches of free space surrounding an amplifier on its sides and top. If the manufacturer recommends a certain clearance, mounting orientation or air flow, follow those recommendations.

Inside the amplifier, HV circuits attract dust

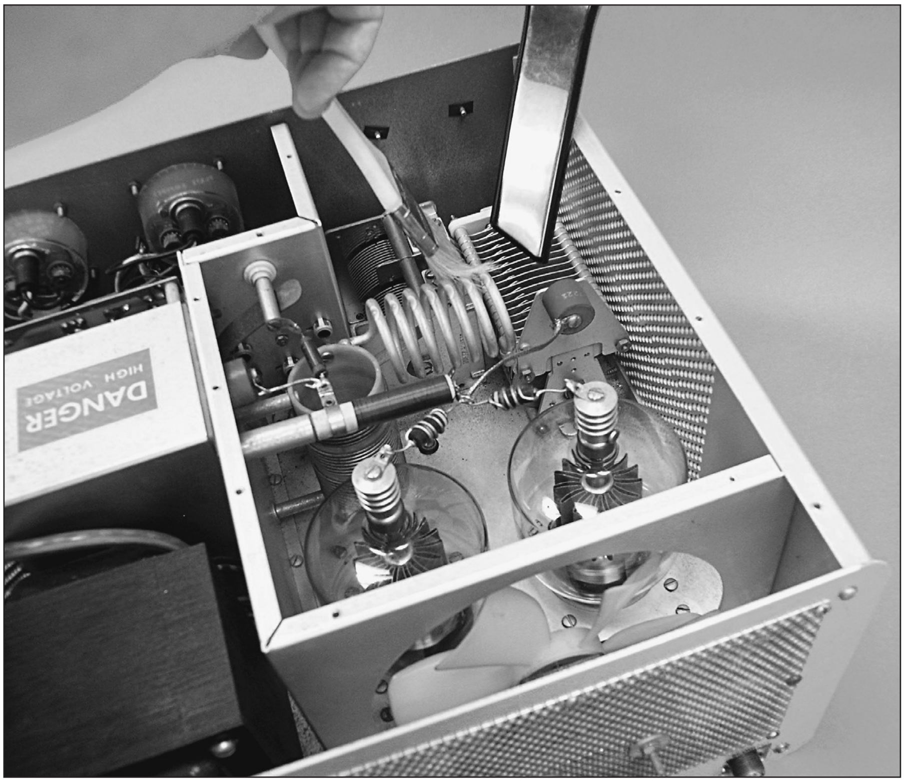

Figure 26.23 — A small paintbrush and a vacuum cleaner crevice attachment make dust removal easy.

that slows heat dissipation and will eventually build up to where it arcs or carbonizes. Use the vacuum cleaner to remove any dust or dirt. If you find insects (or worse) inside the amp, try to determine how they got in and plug that hole. Window screening works fine to allow airflow while keeping out insects. While you're cleaning the inside, perform a visual inspection as described in the next section.

Vacuuming works best with an attachment commonly known as a crevice cleaner. **Figure 26.23** shows a crevice cleaning attachment being used with a small paintbrush to dislodge and remove dust. The brush will root dust out of tight places and off components without damaging them or pulling on connecting wires. Don't use the vacuum cleaner brush attachment; they're designed for floors, not electronics. Some vacuums also have a blower mechanism, but these rarely have enough punch to clean as thoroughly as a brush. Blowing dust just pushes the dust around and into other equipment.

If you can't get a brush or attachment close enough, a spray can of compressed air will usually dislodge dust and dirt so you can vacuum it up. If you use a rag or towel to wipe down panels or large components, be sure not to leave threads or lint behind. Never use a solvent or spray cleaner to wash down components or flush out crevices unless the manufacturer advises doing so — it might leave behind a residue or damage the component.

Cigarette smoke causes its own set of unique problems as tar and nicotine accumulate along with dust and dirt. Removal is difficult at best; commercial solvents such as *Krud Kutter* can be thinned 4-to-1 and will remove the gummy deposits. In extreme cases, disassemble the amplifier (remove tube(s), power transformer and meters) and wash it in a sink with soap and water. Be careful to protect or remove meters and other components that can be damaged by water. Thoroughly dry the amplifier in warm air. Re-lubricate variable capacitors, variable inductors, and any rotary controls.

INSPECTION

Remove any internal covers or access panels and...stop! Get out the grounding stick (see the **Power Sources** chapter), clip its ground lead securely to the chassis, and touch every exposed connection. Now, using a strong light and possibly a magnifier, look over the components and connections. Use all of your senses to analyze the interior — smell, look, listen.

Amplifiers have far fewer components than transceivers, so look at every component and insulator. Look for cracks, signs of arcing, carbon traces (thin black lines), discoloration, loose connections, melting of plastic, and anything else that doesn't look right. This is a great time to be sure that mounting and grounding screws are tight. Does anything smell burnt? Learn the smells of overheated components. Make a note of what you find, repair or replace — even if no action is required. If the amplifier was recently powered up, an infrared thermometer can spot components that were running hot. Or you may hear a crackling or sizzling noise from heat —not a good sign! Try to isolate the source of the noise.

ELECTRICAL COMPONENTS

Let's start with the power supply. There are three basic parts to amplifier power supplies — the ac transformer and line devices, the rectifier/filter, and the metering/regulation circuitry. (See the **Power Sources** chapter for more information.) Transformers need little maintenance except to be kept cool and be mounted securely, but inspect for overheating, discoloration, or seepage from insulation or tar. Line components such as switches, circuit breakers and fuses, if mechanically sound and adequately rated, are usually electrically okay as well. Check fuses and switches with a multimeter.

Rectifiers and HV filter capacitors require occasional cleaning. Look for discoloration around components mounted on a printed circuit board (PCB) and make sure that all wire connections are secure. HV capacitors are generally electrolytic or oil and should show no signs of leakage, swelling or outgassing around terminals.

Components that perform metering and regulation of voltage and current can be affected by heat or heavy dust. If there has been a failure of some other component in the amplifier — such as a tube — these circuits can be stressed severely. Resistors may survive substantial temporary overloads but may show signs of overload such as discoloration or swelling — and change value. Verify the correct value with a multimeter against the color code; if it is not readable or reads erratically, replace the component.

Amplifiers contain two types of relays — control and RF. Control relays switch ac and dc voltages and do not handle input or output RF energy. The usual problem encountered with control relays is oxidation or pitting of their contacts. A burnishing tool can be used to clean relay contacts. In a pinch a strip of ordinary paper can be pulled between contacts gently held closed. Avoid the temptation to over-clean silver-plated relay and switch contacts. It is easy to remove contact plating with excessive polishing, and while silver-plated relay and switch contacts may appear to be dark in color, oxidized silver (black) is still a good conductor. Once the silver's gone, it's gone; contact erosion will then be pervasive.

If visual inspection shows heavy pitting or discoloration or resistance measurements show the relay to have intermittent contact quality, it should be replaced.

If the resting current is too high or intermittent, check power relays for good contact from the bias supply. On some older amplifiers, the relay coil is used as a resistor to create a voltage drop that cuts off the tube. If the relay coil covering is discolored, measure the resistance of the coil and possibly replace it.

RF relays are used to perform transmit/receive (TR) switching and routing of RF signals through or around the amplifier circuitry. Amplifiers designed for full break-in operation will usually use a high-speed vacuum TR relay. Vacuum relays are sealed and cannot be cleaned or maintained. When you replace RF relays, use a direct replacement part or one rated for RF service with the same characteristics as the original.

If the SWR measured between the transceiver and the amplifier suddenly increases, is erratic, or QSK (break-in) stays in the transmit state or is just open in receive, check the RF relay contacts.

Cables and connectors are subjected to heavy heat and electrical loads in amplifiers. Plastics may become brittle and connections may oxidize. Cables should remain flexible and not be crimped or pinched if clamped or tied down. Gently wiggle cables while watching the connections at each end for looseness or bending. Connectors can be unplugged and reseated once or twice to clear oxide on contact surfaces.

Carefully inspect any connector that seems loose. Be especially careful with connectors and cables in amplifiers with power supplies in separate enclosures from the RF deck. Those interconnects are susceptible to both mechanical and electrical stress, and you don't want an energized HV cable loose on the operating desk. Check the electrical integrity of those cables and make sure they are tightly fastened.

As with relays, switches found in amplifiers either perform control functions or route RF signals. Adequately rated control switches, if mechanically sound, are usually okay. Band switches are the most common RF switch — usually a rotary phenolic or ceramic type. A close visual inspection should show no pitting or oxidation on the wiper (the part of the switch that rotates between contacts) or the individual contacts. Arcing or overheating will quickly destroy rotary switches. **Figure 26.24** shows a heavy-duty band switch that has suffered severe damage from arcing.

Slight oxidation is acceptable on silver-plated switches. Phosphor-bronze contacts can sometimes be cleaned with a light scrub from a pencil eraser, but plating can be easily removed, so use caution with this method and be sure to remove any eraser crumbs.

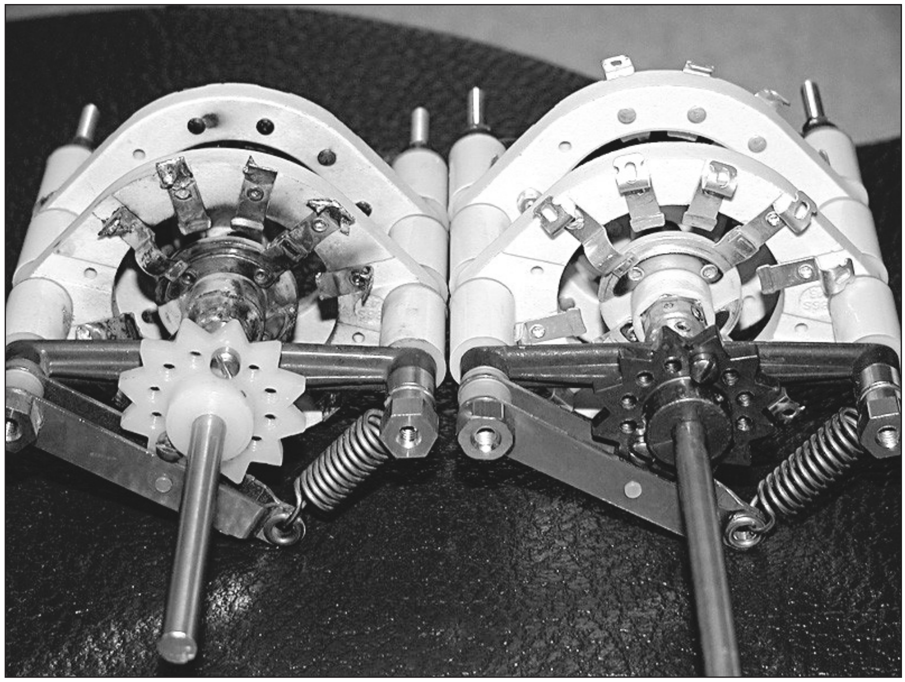

Figure 26.24 — The band switch section on the left clearly shows the signs of destructive arcing.

Wafer Switch Repair

Because they are often custom parts, replacements for individual wafers and contacts for rotary switches can be difficult or impossible to find. You may be able to find switches with the same size contacts, however. These can serve as replacements for contacts on the damaged switch. Save pieces of the damaged switch, since they can be used for parts.

Start by disassembling the damaged switch. If it is on a shaft, there are usually two threaded rods holding it together. Save all pieces. Note the order in which flat and lock washers are used. Taking a close-up photo or making a careful drawing is a good idea. Take care to save all the parts. Place the damaged wafer on your work surface with the hollow-side of the rivet facing up. Use a drill bit just a bit larger than the rivet. Drill-out the rivet at low speed, using just enough pressure to cut off the lip of the rivet – do not drill into the contact itself. Remove the burned contacts first to get a "feel" for how to do it without damaging the contact.

Now disassemble the switch to be used for part replacement and once again, save all the parts for future use. Once the wafers are in-hand, inspect them and pick the best ones to be used as replacements. Remove the replacement contacts in the same way as the damaged contacts were removed.

Now replace the damaged contacts with the replacements using #2-56 screws and nuts (smaller switches may require even smaller hardware), being careful not to over tighten the screws and crack the ceramic or phenolic wafer; "just tight" is good enough. Use a dab of LockTite Red (or paint or fingernail polish) to secure. **Figure 26.A1** shows a wafer that has been repaired using this technique.

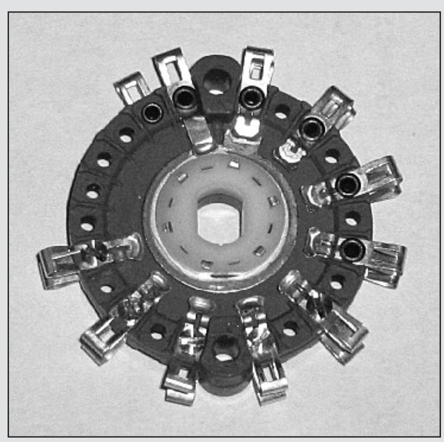

Figure 26.A1 — Five contacts starting at the 4:30 position on the wafer have been replaced using contacts removed from another switch and #2-56 hardware. [Photo courtesy of Matt Kastigar, WØMJ]

Rotary switch contacts cannot be replaced easily, although individual wafer sections may be replaced if an exact matching part can be obtained (see sidebar). De-oxidation chemicals should be applied with a pen-type applicator and not sprayed to avoid absorption by porous phenolics or plastics that can create resistive paths.

When replacing capacitors and resistors, be sure to use adequately rated parts. Voltage and power-handling ratings are particularly important, especially for components handling high RF currents. An RF tank capacitor replacement should be checked carefully for adequate RF voltage and current ratings, not just dc. HV resistors are generally long and thin to prevent arcing across their surfaces. Even if a smaller (and cheaper) resistor has an equivalent power rating, resist the temptation to substitute it. In a pinch, a series string of resistors of the appropriate combined value can be used to replace one HV unit. Don't use carbon resistors for metering circuits, use metal or carbon film types. The carbon composition types are too unstable. Electrolytic capacitors also have a temperature rating, usually 85 or 105 °C; use the higher rating if available.

If you are repairing or maintaining an old amplifier and manufacturer-specific parts are no longer available, the ham community has many sources for RF and HV components. Fair Radio Sales (**www.fairradio. com**) and Surplus Sales of Nebraska (**www. surplus-sales.com**) are familiar names. Hamfests and websites often have amplifier components for sale. (See the **RF Power Amplifiers** chapter's sidebar on using surplus or used parts for amplifiers.) You might consider buying a non-working amplifier of the same model for parts. MFJ (**www.mfjenterprises.com**) sells some parts that are used in the Ameritron brand of amplifiers — you may be able to substitute.

TUBES

Good maintenance starts with proper operation of the amplifier. Follow the manufacturer's instructions for input drive levels, duty cycles, tuning and output power level. Frequently check all metered voltages and zcurrent to be sure that the tubes are being operated properly and giving you maximum lifetime. The manufacturer spent time and effort to develop the manual — read it! If you do not have one, do a web search (or call the manufacturer) and get one. It is time well spent.

The internal mechanical structures of tubes generally do not deal well with mechanical shock and vibration, so treat them gently. The manufacturer may also specify how the amplifier is to be mounted, so read the operating manual. Tubes generate a lot of heat, so it's important that whatever cooling mechanism, employed is kept at peak efficiency. Airways should be clean, including between the fins on metal tubes. All seals and chimneys should fit securely and be kept clean. Wipe the envelope of glass tubes clean after handling them — fingerprints should be removed to prevent baking them into the surface. On metal tubes that use finger-stock contacts, be sure the contacts are clean and make good contact all the way around the tube. Partial contact or dirty finger stock can cause asymmetric current and heating inside the tube, resulting in warping of internal grids and possibly causing harmonics or parasitics.

Plate cap connections and VHF parasitic suppressors should be secure and show no signs of heating. Overheated parasitic suppressors may indicate that the neutralization circuit is not adjusted properly. Inspect socket contacts and the tube pins to be sure all connections are secure, particularly high-current filament connections. Removing and inserting the tubes once or twice will clean the socket contacts.

While the tubes are removed, check the pins for melted solder — this is common on over-heated 3-500Z tubes. If needed, resolder with silver solder, and be careful not to use too much solder, which might expand the diameter of the pin.

Adjustments to the neutralizing network, which suppresses VHF oscillations by negative feedback from the plate to grid circuit, are rarely required except when you are replacing a tube or after you do major rewiring or repair of the RF components. The manufacturer will provide instructions on making these adjustments. If symptoms of VHF oscillations occur without changing a tube, then perhaps the tube characteristics or associated components have changed. Parasitic oscillations in high-power amplifiers can be strong enough to cause arcing damage. Perform a visual inspection prior to readjusting the neutralizing circuit.

Metering circuits rarely fail on their own, but they play a key part in maintenance. By keeping a record of normal voltages and currents, you will have a valuable set of clues when things go wrong. Record tuning settings, drive levels, and tube voltages and currents on each band and with every antenna. When settings change, you can refer to the notebook instead of relying on memory.

MECHANICAL

The most common faults appear with the moving parts: connectors, relays and switches. Thermal cycling and heat-related stresses can result in mechanical connections loosening over time or material failures. Switch shafts, shaft couplings (especially if they are plastic) and panel bearings all need to be checked for tightness and proper alignment. All mounting hardware needs to be tight, particularly if it supplies a grounding path. Examine all panel-mounted components, particularly RF connectors, and be sure they're attached securely. BNC and UHF connectors mounted with a single nut in a round panel hole are notorious for loosening with repeated connect/disconnect cycles. Rubber and plastic parts are particularly stressed by heat. If there are any belts, gears or pulleys, make sure they're clean and that dust and lint are kept out of their lubricant. Loose or slipping belts should be replaced. Check O-rings, grommets and sleeves to be sure they are not brittle or cracked. If insulation sleeves or sheets are used, check to be sure they are covering what they're supposed to. Never discard them or replace them with improperly sized or rated materials.

Enclosures and internal shields should all be fastened securely with every required screw in place. Watch out for loosely overlapping metal covers. If a sheet metal screw has stripped out, either drill a new hole or replace the screw with a larger size, taking care to maintain adequate clearance around and behind the new screw. Or, if space permits, a "speed" or clip nut can sometimes be used. These are available from auto parts or home improvement stores, usually in the "specialty hardware" section.

Tip the amplifier from side to side while listening for loose hardware or metal fragments, all of which should be removed.

Clean the front and back panels to protect the finish. If the amplifier cabinet is missing a foot or an internal shock mount, replace it. A clean unit with a complete cabinet will have a significantly higher resale value, so it's in your interest to keep the equipment looking good.

SHIPPING

When you are traveling with an amplifier or shipping it, some care in packing will prevent damage. Improper packing can also result in difficulty in collecting on an insurance claim, should damage occur. The original shipping cartons are a good method of protecting the amplifier for storage and sale, but they were not made to hold up to frequent shipping. If you travel frequently, it is best to get a sturdy shipping case made for electronic equipment. Pelican (**www.pelican-shipping-cases.com**) and Anvil (**www.anvilsite.com**) make excellent shipping cases suitable for carrying amplifiers and radio equipment.

Some amplifiers require the power transformer to be removed before shipping. Check your owner's manual or contact the manufacturer to find out. Failure to remove it before shipping can cause major structural damage to the amplifier's chassis and case.

Tubes should also be removed from their sockets for shipment. It may not be necessary to ship them separately if they can be packed in the amplifier's enclosure with adequate plastic foam packing material. If the manufacturer of the tube or amplifier recommends separate shipment, however, do it!

CLEANING AND MAINTENANCE PLAN

For amateur use, there is little need for maintenance more frequently than once per year. Consider the maintenance requirements of the amplifier and what its manufacturer recommends. Review the amplifier's manuals and make up a checklist of what major steps and tools are required.

TROUBLESHOOTING

A benefit of regular maintenance will be familiarity with your amplifier should you ever need to repair it. Knowing what it looks (and smells) like inside will give you a head start on effecting a quick repair.

The following discussion is intended to illustrate the general flow of a troubleshooting effort, not be a step-by-step guide. Before starting on your own amplifier, review the amplifier manual's "Theory of Operation" section and familiarize yourself with the schematic. If there is a troubleshooting procedure in the manual, follow it. **Figure 26.25** shows a general-purpose troubleshooting flow chart. Do not swap in a properly functioning tube or tubes until you are sure that a tube is actually defective. Installing a good tube in an amplifier with circuit problems can damage a good tube.

Many "amplifier is dead" problems turn out to be simply a lack of ac power. Before even opening the cabinet of an unresponsive amplifier, be sure that ac is really present at the wall socket and that the fuse or circuit breaker is really closed. If ac power is present at the wall socket, trace through any internal fuses, interlocks and relays all the way through to the transformer's primary terminals. If the amplifier operates from 240-V circuits, be sure you check both hot wires. (See the **Safety** chapter for more information about ac wiring practices.)

Hard failures in a high-voltage power supply are rarely subtle, so it's usually clear if there is a problem. When you repair a power supply, take the opportunity to check all related components. If all defective components are not replaced, the failures may be repeated when the circuit is re-energized.

Rectifiers may fail open or shorted — test them using a DMM diode checker. An open rectifier will result in a drop in the high-voltage output of 50% or more but will probably not overheat or destroy itself. A shorted rectifier failure is usually more dramatic and may cause additional rectifiers or filter capacitors to fail. If one rectifier in a string has failed, it may be a good idea to replace the entire string as the remaining rectifiers have been subjected to a higher-than-normal voltage.

High-voltage filter capacitors usually fail shorted, although they will occasionally lose capacitance and show a rise in ESR (equivalent series resistance). Check the rectifiers and any metering components — they may have been damaged by the current surge caused from a short circuit.

Power transformer failures are usually due to arcing in the windings, insulation failures, or overheating. High-voltage transformers can be disassembled and rewound by a custom transformer manufacturer.

Along with the plate supply, tetrode screen supplies also occasionally fail. The usual cause is the regulation circuit that drops the voltage from the plate level. Operating without a screen supply can be damaging to a tube, so be sure to check the tube carefully after repairs.

If the power supply checks out okay and the tube's filaments are not lit, check the tube socket and the pins on the tube itself — overheating can cause solder to flow, resulting in intermittent failure. If the tube's filament is lit, check the resting or bias current. If it is excessive or very low, check all bias voltages and dc current paths to the tube, such as the plate choke, screen supply (for tetrodes) and grid or cathode circuits.

If you do not find power supply and dc problems, check the RF components or RF deck. Check the input SWR to the amplifier. If it has changed, then you likely have a problem in the input circuitry (overheated coil, shorted capacitor or bad switch contact) or one or more tubes have failed. Perform a

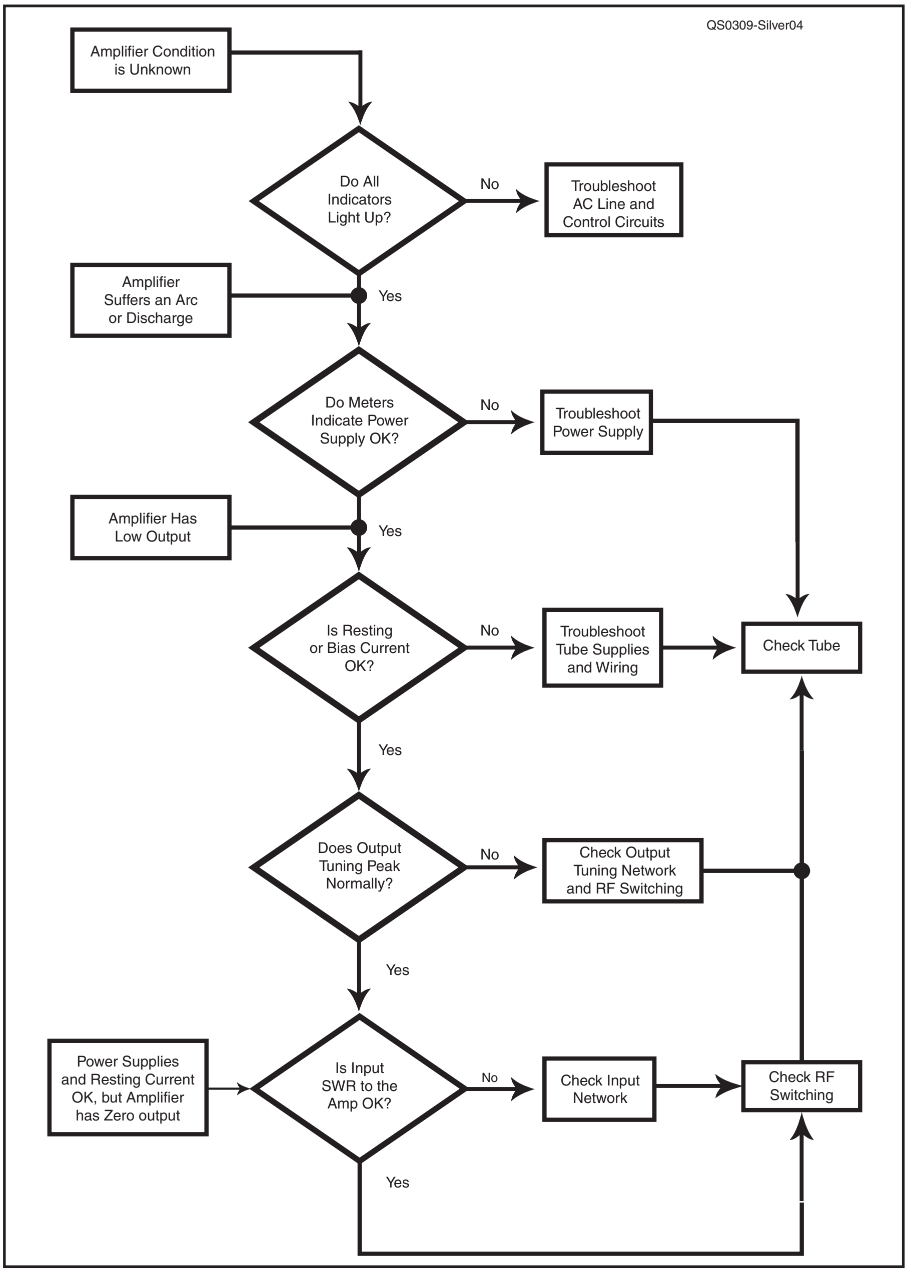

Figure 26.25 — This general-purpose flow chart will help identify amplifier problems. For solid-state units, substitute "Check Output Transistors" for "Check Tube."

visual check of the input circuitry and the band switch, followed by an ohmmeter check of all input components. Use an SWR analyzer or a dip oscillator to see if the input tuning has changed, indicating a possible bad tuning network component in the input circuits. If input SWR is normal and applying drive does not result in any change in plate current, you may have a defective tube, tube socket or connection between the input circuits and the tube.

Check the TR control circuits and relay. If plate current changes, but not as much as normal, try adjusting the output tuning circuitry. If this has little or no effect, the tube may be defective or a connection between the tube and output circuitry may have opened. If retuning has an effect, but at different settings than usual, the tube may be defective or there may be a problem in the tuning circuitry. A visual inspection and an ohmmeter check are in order.

SOLID STATE AMPLIFIERS

Almost all diagnostic techniques used for tube amplifiers are also applicable to solid state amplifiers. Input and output circuits are very similar. Power supplies are usually lower voltage (but high current).

Power supplies typically can be checked with a multimeter for voltage, but current will require reading the voltage drop across a low-value, high-wattage resistor (this can cause problems from the voltage drop) or using a clamp-on current probe. Bias adjustments typically are made with a potentiometer on a voltage regulator circuit (you'll need the schematic or user's manual), and resting current needs to be checked and verified against the manufacturer's specifications.

As with tubes, heat is the enemy. Keep all ventilation openings clear and clean. Check fans for proper operating and speed. Remove any dust or dirt buildup, especially on heat sinks and transistor packages.

Bipolar transistors can be checked with a multimeter (see the **Component Data and References** chapter), as can MOSFETS, which are now more common in RF amplifiers. Replacements will require de-soldering the old part, cleaning up the PC board, and installation of the new part. If the transistors are mounted against a heat sink, use a thin, bubble-free film of heat sink compound between the transistor and heat sink. Make sure all screws are in place and tight. If shoulder washers are used to insulate screws, be sure they are used when the amplifier is reassembled.

POWERING UP OLD AMPLIFIERS

When a piece of equipment has been idle for a long period of time, proper care must be taken to "revive" it. DO NOT just "plug it in" and "power it up" — the results will most likely be smoke and sparks! This is especially true for amplifiers with high-voltage power supplies. (See Powering Up the Equipment in the section Repair and Restoration of Vintage Equipment.)

First, examine the device for physical damage such as bent sheet metal or dents. Clean metal work and panels is usually a good sign. Assuming it is ac-powered, look at the line cord for cuts, scuffs, or cracks, then bend it between your fingers and listen for "cracking." If it is dried out or brittle, replace it before proceeding. If the line cord is okay, tie a piece of wire through the plug's pins so that it cannot be plugged in to a receptacle. Make sure the plug is the right one for the input voltage (120 or 240 V). Check the fuses (if present) — a good indication of condition when last used.

Open the cabinet, remove the tube(s) and store in a safe place. Look closely for any irregularities such as dark PC board areas; discolored resistors; breached, swollen, or leaky capacitors; disconnected wires; loose components or screws; or cracked components or hardware. Begin with these and replace as required. Verify that all of the power supply connections are in order, including that power transformer connections are configured for the proper voltage.

Typically, old electrolytic capacitors, even if otherwise good, have dried out and need attention. They can be tested with a multimeter for shorts (or open), or with an ESR meter if available. These are best replaced if the amplifier is really old or if they don't charge up properly in the power-up test (see below and this chapter's section on repairing vintage equipment).

Use a multimeter to test for shorts to ground in the power supply section. With the power switch in the ON position (still not attached to ac power), measure resistance across the pins of the ac plug. It should read 4 to 5 Ω if it is connected to the primary of a transformer and open when the power switch is OFF. If you measure anything other than an open circuit, check for decoupling capacitors on the ac line that might be leaky. Check the secondary resistance of the transformer — it will be higher in resistance. Then work your way to the rectifier and filter capacitors and any chokes.

Check the resistance across the input and output RF connectors. They should be open or nearly open depending on the input or output network type. (Some amplifiers have an RF choke across the output connector that will present a low resistance.) Check the resistance of the HV plate connections of the tubes to ground — it should be open (the plate capacitors may be observed charging up).

If all looks good and it is possible to do so, disconnect the rectifier board or assembly and check the transformer output windings. Then check any interlock components that might have to be closed or opened (depending on function).

Before starting power-up tests, *make sure* your multimeter is rated for the voltage. If not, don't use it as the meter could be destroyed, or an arc through the meter or its leads (called *flashover*) can present a severe shock hazard.

Using a variable transformer (such as a Variac), bring up input power slowly to about 25% of rated input voltage. The secondary voltage of the transformer should be 25% of the recommended output. (Make high voltage measurements either hands-free or with one hand not touching anything.) Because full output voltage will exceed the maximum rating of most multimeters, disconnect the multimeter unless you are using a high-voltage probe. Increase the voltage slowly to full input while watching the transformer — it should not get hot or make noise. Use an infrared thermometer to avoid direct contact but verify the transformer does not get hot without a load.

Next, power down and reconnect the rectifier / filter board or assemblies. Using the variable transformer, start at 25% input voltage again. If the amplifier has a meter with an HV or B+ position, look for about 25% of the normal voltage reading. Dial lights might just barely light. Leave the power supply to "cook" for a few hours, monitoring it closely. Initially, there will be a high current surge that will slowly drop after the electrolytic filter capacitors start to reform their dielectric layer. When the current drops, bump the voltage up 10 to 20 V, wait a half hour, then turn it up again, monitoring the power supply with each increase. Continue until you have reached full input voltage.

When full power supply high voltage has been achieved, the electrolytic caps should be reformed and the dial lights should be at full brightness. If at any time there is smoke, crackling noise or sparks, disconnect at once, discharge the capacitors, and investigate the issue(s).

Once the power supply is up and running, disconnect the plate B+ lead from the output of the rectifier / filter. In order to check filament voltage, solder temporary wires to the filament socket pins and route them out of the amplifier cabinet. Insert the tube(s), close the cabinet (checking the interlock safety switches), and power up. Quickly verify the filament voltage — it should be within 5% of the specified voltage; if not, power off and investigate. Check the fan(s) for proper operation and air flow.

Tubes get gassy and may arc internally when first powered up after a long period of storage; leave the B+ disconnected and let the tubes "cook" for a few hours. If the tube has a "getter," this may activate it to remove gas. Not all power tubes have a getter — check the data sheet for your tube.

Using lots of caution and a high-voltage probe, check that there is no dc voltage at the output RF connector — if the plate coupling capacitor is shorted, there may be full B+ on the amplifier output!

Power down, wait for the HV / B+ to read zero, and open the cabinet. Use a grounding stick to *be sure* the B+ is at zero, then reconnect it (see the **Power Sources** chapter for safety tips on working with high-voltage power supplies). Put the plate caps on, reattach the cover, and power it up. Listen and watch (if you can see the tubes) for any issues. If you notice anything unusual, stop at once and investigate (after discharging the high voltage, of course). If all is well, monitor the amp and let it cook for a few hours.

After a thorough test, power the amp off, let it sit overnight, then power it up the next day. Check the idling current for the recommended value once again.

Connect the amp to a dummy load that can handle full power output. Put the amp in transmit mode. The idling current should be the recommended value. Switch to standby. Connect a transmitter set for low output (about 20 W) and drive the amplifier. At low drive, the output should be proportional to the input times the gain. If all goes well, apply more drive until full output is achieved. At this point, if the tube is bad, it may fail to reach full power or it may arc. Listen and carefully verify all operations.

26.10 Antenna Systems

This section is an abbreviated version of the Antenna System Troubleshooting chapter of the *ARRL Antenna Book* which was added to the 22nd edition. Because of the enormous variety of antenna systems, general guidelines must be presented, but the successful troubleshooting process usually follows a systematic approach just as for any other radio system.

26.10.1 Basic Antenna Systems

Start with an inventory of the antenna system. Any of these can be the cause of your problem: supports, insulators, elements, feed point, balun (if any), feed line, grounding or transient protectors, impedance matching and switching equipment, RF jumper cables at any point. As with any troubleshooting process, be alert for mistaken or loose connections, loose or disconnected power and control cables, wires touching each other that shouldn't be, and so forth. Reduce the antenna system to the simplest system with the problem and it will likely look something like the system in **Figure 26.26**.

It is particularly important to remember that your station ground is often part of the antenna system. The length of the connection between the equipment ground bus and the ground rod is usually several feet at minimum, which can be an appreciable fraction of a wavelength on the higher HF bands. This can greatly affect tuning if there is common-mode current on the feed line or if a random-wire or end-fed type of antenna is being used. If touching equipment enclosures or the ground wire affects SWR or impedance readings, that will affect your antenna measurements as well.

DUMMY-LOAD TESTING

Begin by replacing components of your antenna system with a dummy load, starting at the output of the radio using a known-good jumper cable. Verify that the radio works properly into a 50 Ω load using a known-good directional wattmeter. Then move the dummy load to the output side of any antenna tuning or switching equipment, one component at a time, until you have replaced the antenna

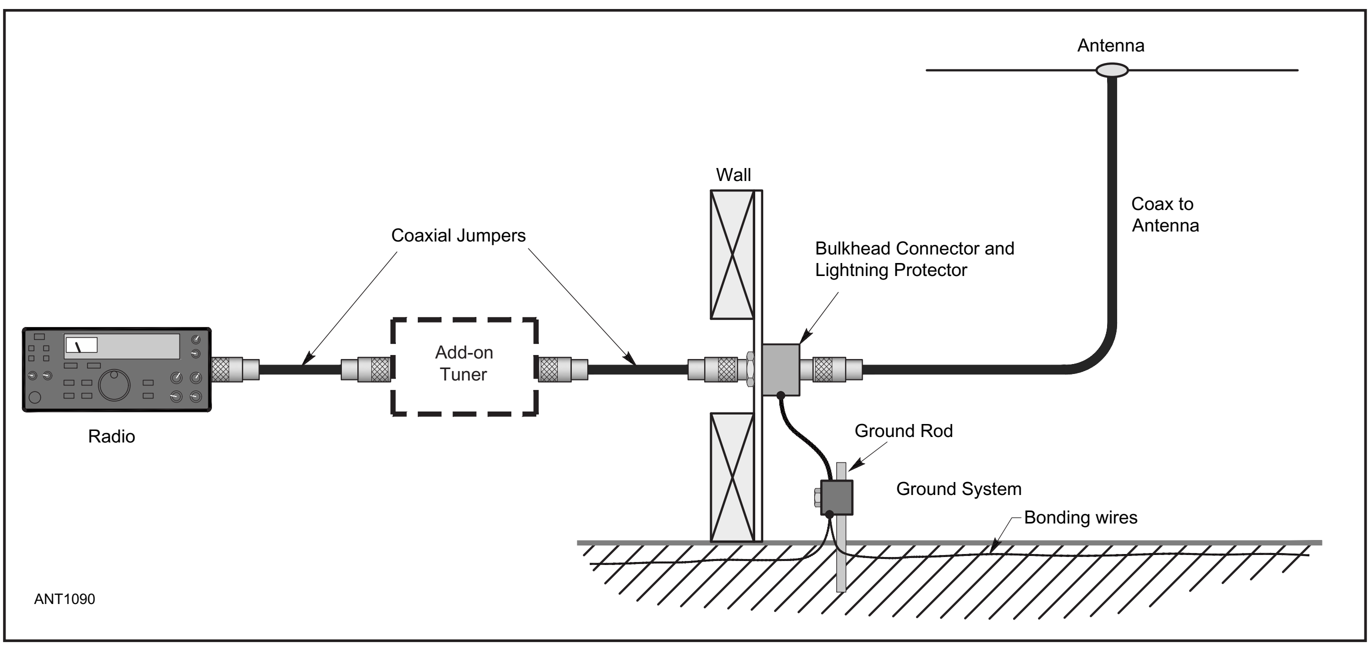

Figure 26.26 — A typical simple antenna system. An add-on antenna tuner is likely to be used if one is not built in to the radio. More complex antenna systems have all of the same components plus some switching equipment.

feed line with the dummy load. If everything checks OK to this point, the problem is in the feed line or antenna. Don't forget to verify that the problem with the antenna is still present after each dummy load test. If the problem was a loose or intermittent connection, it is likely that swapping the dummy load in and out changed or eliminated the problem.

ANTENNA VISUAL INSPECTION

Now it is time to perform a visual inspection of the feed line and antenna itself. Start with the feed line connector at the last point where the dummy load was swapped in. Disassemble the connector and inspect it for damage from water or corrosion. If either are present, replace the connector and check the condition of the cable before proceeding. Note that if water can get into the cable at the antenna's elevated feed point, it is not unknown for it to flow downward through the braid both by gravity and by capillary action all the way to the shack! If the cable braid is wet at both ends, the cable must be replaced.

If you have a wire antenna, lower it and make a visual inspection of all the pieces:

• Cut away the waterproofing around the coax termination and inspect for water and/or corrosion.

• On the insulators at each end, there should be no possibility of contact between the antenna wire and the supporting wire/ropes.

• If there are any splices in the wire elements, they should be well crimped or soldered.

• At the center insulator, there should be no possibility of contact between the element wires.

• At the balun or coax connection the element connections should be soldered or firmly connected.

If you have a Yagi or vertical antenna, similar steps are required. Carefully check any feed point matching assembly, such as a gamma match, hairpin, or stub and make sure connections are clean and tight.

ANTENNA TEST

Assuming any mechanical problems have been rectified, proceed to retest the antenna and feed line. Replace the antenna with a dummy load and check the feed line loss with a wattmeter or antenna analyzer at the antenna end of the feed line. If the feed line checks out OK, the problem must be in the antenna. Reattach the feed line to the antenna and verify that the problem remains. Note that for wire antennas lowered to near ground level, the resonant point will change — this is to be expected.

If the problem is still present, repeat the visual inspection at a closer level of detail. Check all dimensions and connections. Double-check any telescoping sections of tubing, transmission line stubs, in-line coax connectors clamped connections between wires and between wires and tubing. If possible, give joints and connections a good shake while watching for intermittent readings on the wattmeter or antenna analyzer. If you cannot see inside a component or assembly, perform resistance tests for continuity. Remember to identify your signals, since you are testing on the air at this point in the process.

The next step is to reinstall or raise the antenna at least ¼-wavelength off the ground and verify that the problem remains. If you have repaired the antenna, perform a re-check at this point to be sure everything is in good working order before returning the antenna to full height. Once you have re-installed the antenna, including full weatherproofing of any coaxial cable terminations or connectors, record in the shack notebook your measurements of the antenna, along with what the problem was discovered to be and how you repaired it.

AM Broadcast Interference to Antenna Analyzers

Living or testing within a couple of miles of an AM broadcast station can create a lot of problems for the sensitive RF detectors in portable antenna analyzers. This type of RFI usually appears as values of SWR and impedance that don't change with frequency or that change in unexpected ways or an upscale meter reading that varies with the station modulation. The analyzer SWR reading will not agree with SWR measured by using a directional wattmeter and more than a few watts of power. The solution is sometimes to use a broadcast-rejection filter (available from analyzer manufacturers) although this tends to color measurements a bit and typically can't be used for measurements on 160 meters because it is so close to the AM broadcast band. In cases where the station is nearby or on 160 meters, directional wattmeters or analyzers with narrow-band tuned inputs must be used.

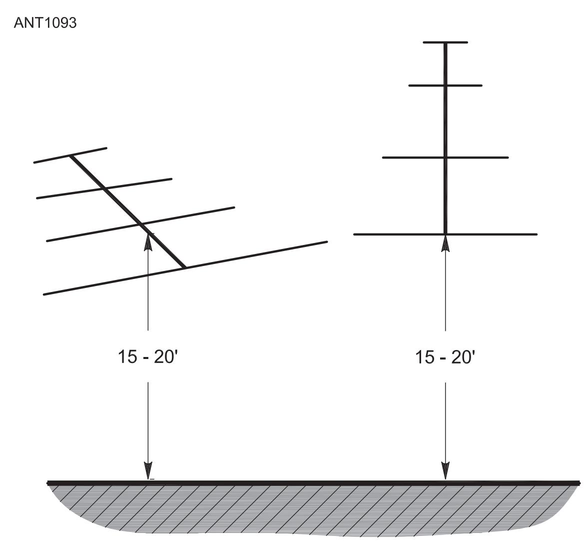

Figure 26.27 — When testing a Yagi or quad antenna, make sure it is at least 15 to 20 feet above ground. If oriented vertically, the reflector should be the closest to ground. Performance will still change as the antenna is raised.

26.10.2 General Antenna Systems

Think of the following topics as a kind of toolbox for troubleshooting. Many of them assume you are testing some type of Yagi or other beam antenna, but the general guidelines apply to all types of antennas

It is important to remember this simple rule for adjustments and troubleshooting: Do the simplest and easiest adjustment or correction *first*, and only *one* at a time.

When making on-air comparisons, select signals that are at the margin and not pushing your receiver well over S9, where it can be difficult to measure differences of a few dB. Terrain has a lot to do with performance as well. If you are comparing with a large station, keep in mind that its location was probably selected carefully and the antennas were placed exactly where they should be for optimum performance on the property.

TEST MEASUREMENTS

A) Test the antenna at a minimum height of 15 to 20 feet (see **Figure 26.27**). This will move the antenna far enough away from the ground (which adds capacitance to the antenna) and enable meaningful measurements. Use sawhorses *only* for construction purposes.

• 15 to 20 feet above ground does not mean 5 feet above a 10 to 15 foot high roof, it means above ground with nothing in between;

• Antenna resonant frequency will shift upward as it is raised;

• Feed point impedance will change with a change in height, which applies to both horizontal and vertical antennas;

• Some antennas are more sensitive to proximity to ground than others;

• Some antennas are more sensitive to nearby conductive objects (such as other antennas) than others.

B) Aiming the antenna upward with the reflector on the ground might coincide with some measurements on rare occasions, but there are no guarantees with this method. The reflector is literally touching a large capacitor (earth) and the driver element is very close, too. Raise the antenna at least 15 to 20 feet off the ground.

C) When using a hand-held SWR analyzer you are looking for the dip in SWR, not where the impedance or resistance meter indicates 50 Ω. (Dip = frequency of lowest SWR value, or lowest swing on the meter.) On the MFJ-259/269 series, the left-hand meter (SWR) is the one you want to watch, not the right-hand meter (impedance).

D) Does the SWR and frequency of lowest dip change when the coax length is changed? If so, the balun might be faulty, as in not isolating the load from the coax feed line.

Additionally, with an added length of coax and its associated small (hopefully small) amount of loss :

• The value of SWR is expected to be lower with the additional coax and,

• The width of the SWR curve is expected to be wider with the additional coax, when measured at the transmitter end of the coax.

E) Be sure you are watching for the right dip, as some antennas can have a secondary resonance (another dip). It is quite possible to see a Yagi reflector's resonant frequency, or some other dip caused by interaction with adjacent antennas.

MECHANICAL

A. Are the dimensions correct? Production units should match the documentation (within reason). When using tubing elements, measure each *exposed* element section during assembly and the element *half-length* (the total length of each half of the element) after assembly. Measuring the entire length is sometimes tricky, depending on the center attachment to the boom on Yagis, as the element can bow, or the tape might not lay flat along the tubing sections. Self-designed units might have a taper error.

B. Making the average taper diameter larger will make the equivalent electrical element longer. This makes the antenna act as if the physical element is too long.

C. Making the average taper diameter smaller will make the equivalent electrical element shorter. This makes the antenna act as if the physical element is too short.

D. If the element is a mono-taper (tubing element is the same for the entire length), larger diameter elements will be physically shorter than smaller diameter mono-taper elements to give the same electrical performance at the same frequency.

E. The type of mounting of the element to the boom affects the element length, whether it is attached directly to the boom, or insulated from the boom. Incorrect mounting/mounting plate allocation will upset the antenna tuning:

• A mounting plate 4 × 8 inches has an equivalent diameter of approximately 2.5 inches and 4 inches in length for each element half.

• A mounting plate that is 3 × 6 inches has an equivalent diameter of about 1.8 inches and a length of 3 inches for each element half.

• The mounting plate equivalent will be the first section in a model of the element half.

F. In a Yagi, if the elements are designed to be touching, are the elements touching the boom in the correct locations?

G. In a Yagi, if the elements are designed to be insulated, are the elements insulated from the boom in the correct locations?

H. The center of hairpin matching devices (i.e. on a Yagi) can be grounded to the boom.

I. The boom is neutral, but it is still a conductor! The center of a dipole element is also neutral and can be touched while tuning without affecting the reading. With a hairpin match, the center of the hairpin can also be touched while tuning, and touching the whole hairpin might not affect the readings much at all.

PROXIMITY

A. What else is nearby (roof, wires, guy lines, gutters)? If it can conduct at all, it can and probably will couple to the antenna!

B. Does the SWR change when the antenna is rotated? If so, this indicates interaction. Note that in some combinations of antennas, there can be destructive interaction even if the SWR does not change. Computer models can be useful here.

C. What is within ¼ wavelength of the antenna? Imagine a sphere (like a big ball) with the antenna in question at the center of the sphere, with the following as a radius, depending on frequency. Think in three dimensions like a sphere — up and down and front and rear. Any resonant conductor (antenna or not) with the following radii will couple to and probably affect the antenna you are testing or installing.

160 meters = 140 feet
80 meters = 70 feet
40 meters = 35 feet
20 meters = 18 feet
15 meters = 12 feet
10 meters = 9 feet

D. Interaction occurs whether or not you are transmitting on the adjacent antennas. When receiving, it simply is not as apparent as when transmitting.

E. Wire antennas under a Yagi can easily affect it. This includes inverted V dipoles for the low bands and multi-band dipoles. The wire antennas are typically for lower frequency band (s) and will not be affected by the Yagi(s), as the Yagis are for the higher bands.

FEED SYSTEM

The feed system includes:

• the feed line,

• switching mechanisms,

• pigtails from the feed point on the antenna to the main feed line or switch and,

• all feed lines inside the radio room.

The feed system is the *entire connection* between the radio and the feed point of the antenna.

A. Is the feed line (coax) known to be good? (Start with the easiest first.) Check the dc resistance across the cable with the far end open and shorted. Is there water in the coax? This can give strange readings, even frequency-dependent ones. If there is any question, swap the feed line for a known good one and re-test.

B. Are the connectors installed properly? Has a connector been stressed (pulled)? Is the rotation loop done properly to not stress the coax? Is it an old existing loop or a new one? Usually it's alright if new. Type N connectors (especially the older type) are prone to having the center conductor pull out due to the weight of the coax pulling down on the connector. Connectors are easy to do, using the right technique.

C. Is there a barrel connector (a PL-258 dual-SO-239 adapter) in the feed line anywhere? Has a new or different barrel been inserted? These are a common failure point, even with new barrels. The failures range from micro-bridges across the face of the barrel shorting out the center and shield, to resistance between the two ends of the barrel. Have the new barrels been tested in a known feed system? Always test them before installing. Use only quality RF adapters, as these are common system failure points.

D. Is the coax intact and not frayed such that the shield can come into contact with anything? This can cause intermittent problems as the coax shield touches the tower, such as on rotation loops and coax on telescoping towers.

E. Is the tuner OFF on the radio? This is often overlooked when adding a new antenna.

F. Are there any new devices in the line? It might be a good idea to remove everything but the essential items when troubleshooting.

G. Is there a remote antenna switch? Swap to another port.

H. Is there a low pass filter in the line? The filter can be defective, especially on 10 meters, causing strange SWR readings.

26.10.3 Antenna Tuners

Antenna tuners are usually well designed and built with adequately rated parts. Most will last a lifetime, but even QRP power levels can result in arcing if the tuner is trying to match a very high impedance or is accidentally disconnected from an antenna. *Hot switching* can cause damage when contacts in the tuner are moved while transmitting. Lightning transients and excessive power beyond the tuner's ratings cause damage. Frequently adjusted components and contacts can wear out over time or just get dirty. Any of these can cause problems with normal operation.

For more information on the different types and circuits used in tuners, see the section on Matching Impedances in Antenna Systems in the chapter on **Transmission Lines**. Remember that "tuner" is the most common term, but ATU, transmatch, antenna coupler, impedance matching unit, matchbox, and other terms also refer to the same piece of equipment.

If you think your tuner is misbehaving, begin the process of troubleshooting according to the previous section on General Antenna System Troubleshooting. Make sure the problem really is in the tuner! Once you're sure the tuner has a problem, give it a good checkout to get an idea of what you're looking for. Keep notes as you test, since these will provide clues to what the problem may be and also point to tests you should perform after repairs to be sure you've fixed the problem.

Whether the tuner is internal to your transceiver or an external unit, start with a close and detailed visual inspection. Are the connectors clean? Do any connectors look like there has been an arc, or are they discolored from heat or corrosion? If there are multiple antenna connectors, does the unit perform differently when the antenna is connected to different connectors? Are there any loose parts inside that rattle when the unit is tipped or shaken? Smell the unit, too — if anything smells burned, you may have a damaged component inside. These are also excellent inspections to make before buying a used tuner.

Operate the tuner into a dummy load at low and high power. Does it behave the same way at both power levels? Does it operate erratically? Does wiggling any of the feed lines to or from the tuner cause SWR to change at the transmitter output? Operate the tuner into a known-good antenna and feed line, then repeat the tests.

T network tuners have a reputation of being able to "tune up into themselves," meaning they can match even an open circuit because they have such a wide tuning range. This results in very high voltages and currents inside the tuner, creating all sorts of problems.

Once you've put the tuner through its paces, you'll have a better idea of what problems you're facing. It is also worth considering that there may be more than one problem. When you find something wrong and fix it, repeat your tests to see if the problem is still there or has changed.

AUTOMATIC ANTENNA TUNERS

Most of the same components in a manual tuner are present in an automatic tuner along with sensing, selection, and indicating circuits. The most important new moving parts are relays. Automatic tuners are a bit more difficult to diagnose, but by breaking them down into functional parts troubleshooting is straightforward. (This section also applies to the internal antenna tuners common in HF transceivers.)

Typically, automatic tuners have fixed-value capacitors and inductors in an L network. A phase sensor and voltage detectors are read by a microprocessor, which switches in L and C based on an algorithm to arrive at the best SWR match. The inductors and capacitors are switched in or out by relays. In "zero-power" tuners (tuners that do not draw much if any current once tuning is complete) latching relays are used. These remain open or closed once power is removed.

There are three usual symptoms for automatic tuner problems. The tuner may not be able to achieve a match at all and display some kind of error condition. The tuner can "hunt" without stopping for a match according to its control program — you'll hear the relays clicking or buzzing without stopping. Or the tuner will suddenly start re-tuning at higher power levels during transmission because a component or relay is failing.

If the tuner cannot find a match or keeps "hunting" to find a match, the issue is typically a bad relay contact. The controller "thinks" it has the correct L or C value switched-in, but the contact is not being made. A relay driver line can also be open. Also check for a bad interconnect cable between the external antenna connector and the main board.

The most common issue is relay failure. Relays have a coil that is energized to move an *armature* holding the contacts. The usual relay acts as a DPDT switch with a set of NC (*normally closed*) and NO (*normally open)* contacts. To test the relay, first measure the coil resistance. Then energize each relay one at a time and measure the resistance across the contacts with and without power. A coil failure (usually an open circuit) requires relay replacement.

If the coil is good and you can get to the relay contacts, a strip of bond paper and cleaning solution can sometimes clean the contacts of corrosion or oxide. Carefully remove the cover using a hobby knife along the bottom edge, not poking too far into the relay — you do not want to cut the coil winding. In miniature relays in particular, be careful to avoid bending the armature while cleaning. Put some cleaning solution on the paper strip, slide the strip between one set of contacts, hold them together, and slide the strip back and forth. If there is a dark deposit on the paper, keep sliding it back and forth until no additional deposit is seen. Repeat with the other set of contacts. If the contacts are severely pitted or there is large buildup of material on the contact from arcing, the relay should be replaced. Filing the contacts should be avoided because it removes any plating from the contact surfaces.

If the relays are good, the controller may not be actuating them. Check the printed-circuit board traces for burned or open traces. Then work your way back to the driver ICs or transistors and test them; microcontrollers generally cannot drive relays directly. Typically, a transistor is used to energize the relay coils. There should also be a suppressor diode across each coil, which can be tested with a VOM. Replace components as necessary.

MAINTENANCE AND OPERATION

Think of your antenna tuner as the output stage of an amplifier — it contains many of the same type of components, operates at the same power levels, and needs the same care to operate reliably.

In large manual tuners, keep air-variable capacitors, exposed inductors, and switches clean. Dirt and dust can form paths for arcing and cause heat buildup. Remove dust with a gentle brush and vacuum. If the tuner has been in a smoking environment, smoke deposits can accumulate. Clean with a brush first, then apply cleaning solution using a brush and thoroughly dry before operation. Lightly re-oil any bearings in air-variable capacitors after using cleaning solution. Do not put oil on a roller inductor shaft or contact. Check for arcing and broken or heated connections and wires; repair or replace as needed. Use a high-quality cleaning solution on switch contacts, but not to excess, and remove any residue. Check connectors and the cables in and out of the tuner.

Check grounding and bonding. The cabinet of an (external) tuner should be bonded to the transceiver, and to any RF bonding bus or plane in the station. If common-mode RF current is upsetting SWR measurements, use ferrite beads or a toroid to block it.

26.11 Repair and Restoration of Vintage Equipment

When purchasing a classic receiver or transmitter, unless you absolutely know otherwise, assume the radio will need work. Often you can get a top-of-the-line radio needing a bit of inexpensive repair or cleanup. Don't worry — these radios were designed to be repaired by their owners — and curiously, except for cosmetic parts such as cabinets and knobs, parts are much easier to find for 60-year-old radios than a 20-year-old imported transceiver!

Chances are the radio has gone for years without use. Even if it has been recently used, don't completely trust components that might be 60 or more years old. Don't start by plugging in your new acquisition! To do so might damage a hard-to-replace power transformer, or cause a fire.

Instead, if the radio didn't come with its owner's manual, get one. Several *QST* vendors sell old manuals in good condition. K4XL's Boat Anchor Manual Archive (**www2.faculty.sbc.edu/kgrimm/boatanchor**) is probably *the* best free resource for these manuals. Armed with the manual, remove the radio from its cabinet. You very likely will find evidence of unsightly repairs, modifications, or even dangling wires. While modifications aren't necessarily bad, they can certainly add some drama to any necessary subsequent troubleshooting. It's up to you to reverse or remove them.

Another option for working with vintage equipment is to refer to editions of the *ARRL Handbook* published around the time that the equipment was in common use. The circuit design and construction practices described in the *Handbook* are likely to be representative of those in the radio and may provide guidance for troubleshooting, repair, and adjustment. Similarly, the troubleshooting sections and chapters in previous editions provide valuable guidance for working with equipment of the same or earlier vintages.

26.11.1 Component Replacement

Correct any obvious problems such as dangling components. Replace the line cord with a three-wire, grounded plug, if not a transformerless "ac/dc" type as discussed below. If the radio is one with a live chassis, you should operate it from an isolation transformer for safety. If you don't have an isolation transformer, use a voltmeter to determine the orientation of the ac plug that places the chassis at ground potential. Avoid touching the chassis and do not use knobs with set screws that contact metal control shafts. It's also a good idea to add a fuse, if the radio doesn't originally have one. Are we ready to give it the smoke test? Not so fast!

CAPACITOR RATINGS

Obviously, aged components deteriorate, and capacitors are particularly prone to developing leakage or short-circuits with age. There are as many opinions on capacitor replacement as there are radio collectors, but *at the very least* you should replace the electrolytic filter capacitors. Here's why: they *will* short circuit sometime, and when they do, they'll probably take the rectifier tube and the power transformer with them. Modern high voltage electrolytic capacitors are reliable and much smaller than their classic counterparts. Old paper-wax and black plastic tubular capacitors should also be replaced. Again, a short circuit in one of them could take out other components. Modern film capacitors of the appropriate voltage are great replacements. Opinions vary as to whether all should be replaced, but replacements are cheap and you have the radio apart now, so why not? If keeping the original components is important, follow the procedure for using a variable transformer to reform electrolytics as described below.

You can mount the new capacitors under the chassis by mounting a new terminal strip (do *not* just wire them to the old capacitor terminals), you can re-stuff an old electrolytic capacitor's can with new capacitors, or you can buy a new can from places such as **www.hayseedhamfest.com** or Antique Electronics Supply (**www.tubesandmore.com**). In any event, follow the manufacturer's schematic — don't assume that the – (minus) end of the capacitor goes to ground, as in some radios the ground path is through a resistor so as to develop bias for the audio output stage or RF gain circuit. Observe the polarity or you'll soon be cleaning up a stinky mess!

TESTING OLD CAPACITORS

All capacitors have a voltage rating written on the side of the cap, unless it is a small disc. Surplus stores often have bins full of capacitors of unmarked voltage rating. Don't assume they are a high enough voltage to use — check them with a capacitor checker. There are many models out there by Knight Kit, Lafayette, Sencore, and Eico, but the best were the Heathkit IT-11 or IT-28. They are basically the same model but different colors. Both use a 6E5 Magic Eye tube to indicate the status of the capacitor. A selectable voltage from 3 to 600 V dc can be applied to check for leakage and operation. These are good for small disc or paper caps and large electrolytics.

Take the unknown voltage cap and place it in the test terminals. Advance the voltage control from minimum until the eye tube shows it breaking down. You now know what voltage it is good to.

If the capacitor tests good through the 600 V dc range, it probably is a 1000 V dc capacitor. It is best, though, to know for sure the rating of the cap. In tube equipment, most capacitors should be 500 or 1000 V rated. Mouser (**www.mouser.com**) and Digikey (**www.digikey.com**) do still sell caps for those voltage ranges, but they have become very expensive. You could also find new old stock (NOS) capacitors of the correct voltage rating at surplus stores.

REFORMING ELECTROLYTIC CAPACITORS

The best idea is to replace old electrolytic capacitors with a new unit. They are available cheaply in the voltage ranges required and

Using a Tube Tester

Vacuum-tube testers are scarce but can be located through antique or vintage radio associations, audiophile groups, and sellers of tubes.

Most simple tube testers measure the cathode emission of a vacuum tube. Each grid is shorted to the plate through a switch, and the current is observed while the tube operates as a diode. By opening the switches from each grid to the plate (one at a time), we can check for opens and shorts. If the plate current does not drop slightly as a switch is opened, the element connected to that switch is either open or shorted to another element. (We cannot tell an open from a short with this test.) The emission tester does not necessarily indicate the ability of a tube to amplify.

Other tube testers measure tube gain (transconductance). Some transconductance testers read plate current with a fixed bias network. Others use an ac signal to drive the tube while measuring plate current.

Most tube testers also check inter-element leakage. Contamination inside the tube envelope may result in current leakage and shorts between elements. The paths can have high resistance, and may be caused by gas or deposits inside the tube. Tube testers use a moderate voltage to check for leakage. Leakage can also be checked with an ohmmeter using the ×1M range, depending on the actual spacing of tube elements.

more compact and reliable than the original electrolytic caps. If necessary, however, old electrolytics can often be revived by reforming the dielectric using a capacitor checker.

Disconnect the wires attached to the capacitor under test and connect it to the capacitor checker. Start at the lowest voltage rating and let it charge up the capacitor. You will know when it is charged by viewing the eye tube: if it is wide open, the cap is charged; if it is closed, the capacitor is either shorted or still charging. Advance gradually to the next voltage rating and wait until the eye fully opens—take plenty of time for the capacitor to stabilize. Continue on through the voltage ranges; each time it will take longer for the eye to open. The dielectric is being reformed. Finally, when you reach the voltage range of the capacitor and the eye is fully open, the cap has been fully revived and is ready for use.

The same process can be performed with a variable autotransformer (Variac) by advancing it a few volts at a time over several hours, but that is a coarse and unreliable process. A diode must be placed in series with the transformer to convert the ac voltage to dc. Monitor the voltage across the capacitor with a meter. If it suddenly jumps to zero, the capacitor has shorted and is now useless. Usually the capacitor can be revived successfully and will work just fine.

RESISTORS

Over time, carbon resistors in older radios can change value significantly, which can affect circuit operation. Disconnect one end of the questionable resistor and measure it with an accurate ohmmeter. If it is out of tolerance, replace it. Most resistors in the tube era were ½ W or greater. Most circuits today use ¼ W or smaller resistors, which will not dissipate the power tubes produce.

Carbon composition resistors are becoming rarer, but there are still ample quantities of NOS in surplus stores. Be careful about power rating. Use metal oxide resistors if needed. Remember that wirewound resistors are very inductive and not good for RF circuits. They are excellent for power supply circuits and are usually found in the 1 to 25 W range.

REPLACING DIODES

Many old tube radios use rectifier tubes. It is not a good idea to replace these with solid-state rectifiers, as a shorted diode can take out the transformer. Selenium rectifiers, however, are good candidates to replace with a silicon diode. The 1N400x series diode are usually fine for use and very cheap. For higher voltage supplies, be sure to use 1N4007 or higher rated diodes. This may result in higher ouput voltage from the supply. Add a series dropping resistor if necessary to reduce voltage.

TRANSFORMER REPLACMENT

The best bet is to find another radio of the same variety from which you can harvest the transformer. This is especially common in transmitters like the Heathkit DX-35 and DX-40, whose transformers frequently failed. Replacement transformers are generally no longer available. Some companies will rewind transformers, but that is usually prohibitively expensive. Output voltages are quite critical in the design of tube radios, so it is not a good idea to replace a 400 V ac transformer with a 600 V ac unit. It may be best to find a donor radio for a replacement transformer.

WIRE REPLACEMENT

Power cords should be replaced at the first sign of hardening and cracking. It is often a good idea to replace the two-wire power cords with three-wire cords, but this *cannot* be done on ac/dc transformerless radios in which one side of the ac line is connected directly to the chassis! Those must retain the two-wire cords. As noted previously, operating these radios with an isolation transformer is the safest option. If replacing the cord with a two-wire version, the neutral (larger blade) must be connected to the chassis.

Pre-WWII vintage radios often used a cotton covered power cord. To keep the radio as authentic as possible, cotton covered power cords and matching plugs can be found at suppliers such as Antique Radio Supply.

Many early radios had a two-pin power plug with fuses in the plug (the radio has no internal fusing). These are made by Elmeco and are still available (check eBay). Standard 3AG type fuses go in the power plug. Usually a 1 or 2 A fast-blow fuse will work fine except for a higher powered transmitter.

For using PVC-covered wire with terminal strips, solid wire is easier to attach before soldering than stranded wire, although stranded is very usable. You can also use Teflon covered wire that doesn't burn when the soldering iron hits the insulation.

TUBE REPLACEMENT

The sidebar "Using a Tube Tester" explains what a tube tester does. Watch swap meets and garage sales for tube substitution books. Many tubes are interchangeable or similar in purpose. Be sure to document any tube substitutions you make on a vintage radio. Remember that a new tube in the circuit may require re-peaking of the tuned circuits associated with it.

If a tube has a loose tube cap on top, you can easily repair it. Unsolder the cap and make sure that ample wire is still coming from the tube glass envelope. The tube cap should have a tiny hole in the center of the top which the wire will pass through. Mix a small amount of JB Weld epoxy (**www.jbweld.com**) and glue the tube cap back in place. Make sure the wire is sticking out of the hole. After the epoxy has hardened, solder the wire back onto the tube top. Don't let a loose tube cap break it off.

One might be anxious to wipe off the tube and clean it up. Be careful, as you might wipe off the tube number, and then you won't have any idea what the tube is. Many tubes have been lost because they have become unidentifiable. If you do decide to clean up the tube, make sure you steer well clear of the tube number.

Tube sockets and tube pins easily become oxidized, which result in radios not working or being intermittent. It is a good idea to pull each tube and spray the socket with DeoxIT or tuner cleaner. Re-insert the tube and wiggle it around in the socket to rub away any oxidation remaining.

REMOVING AND REPLACING COMPONENTS

Replacing capacitors and/or other components isn't difficult, unless they are buried under other components. The Hallicrafters SX-28 and SX-42 receivers are examples of receivers that have extremely difficult-to-reach components. There are different schools of thought on the proper component replacement method. You can use solder wick and/or a desoldering tool to remove the solder from a terminal, unwrap the wires, and install the new component by wrapping the lead around the terminal and soldering it securely. The proponents of this method point out that this is the preferred military and commercial method. I find it often will needlessly damage other components such as tube sockets and create solder droplets inside of the radio.

Back in the day, radio repairmen clipped out a component leaving a short stub of wire, made little coils in the new lead, then soldered the coiled lead to the old stub. This is a much faster, easier and neater method. Refer to books and websites on repairing vintage equipment for other useful tips and tricks.

26.11.2 Powering Up the Equipment

Before applying any power, use a VOM and measure the resistance from the B+ line to ground. Filter capacitors will cause an initial low resistance reading that increases as the capacitors charge. If the resistance stays low or does not increase beyond tens of kΩ, find the short circuit before you proceed.

DETERMINING THE RIGHT INPUT AC VOLTAGE

Vintage radios were often designed for use with lower ac mains voltages than are the standard today. If they are powered from 120 V ac, the resulting higher voltages can burn out filaments and overload the plate and screen

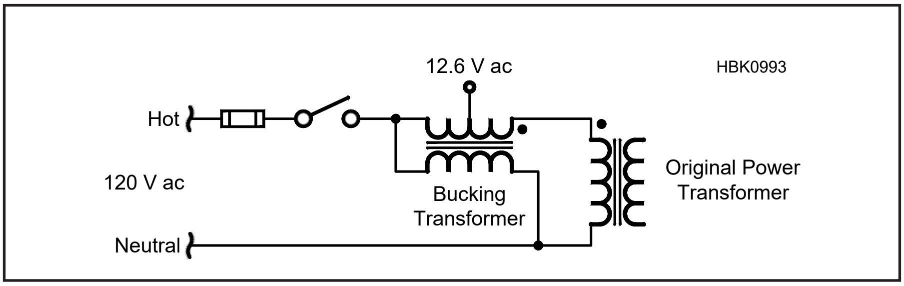

Figure 26.28 — The bucking transformer secondary is connected out of phase with the radios power transformer's primary. This reduces voltage output from the power transformer and avoids over-voltage stress on the radio's tubes and other components.

circuits. Here's how to find out what voltage the radio was designed for:

• Remove all tubes and determine the proper filament voltage for one of them.

• Connect a voltmeter to the filament pins of the tube for which filament voltage is known.

• Using a Variac to power the radio, slowly increase voltage until the filament voltage matches the specified voltage for the tube.

• Measure the input voltage to the radio. That is the ac voltage from which the radio should be powered. If the input voltage is 115 V ac or lower, a bucking transformer can be used to reduce the input voltage.

Wiring for a bucking transformer is shown in **Figure 26.28**. The bucking transformer's primary is connected to the regular input ac voltage. Its secondary is connected in series and out of phase with the radio's power transformer primary. That reduces the input voltage to the power transformer primary so the output voltages are closer to what the components are rated for. Since phasing of a transformer secondary may not be obvious, hook the transformers up and measure output voltage from the radio's power transformer filament winding. If it has increased, reverse the connections for the bucking transformer secondary.

A small filament transformer with a secondary rating of 3 to 5 A will do for most radios. (Large radios may require transformers with higher current ratings.) To power a radio designed for 115 V ac from 120 V ac, use a 5 V or 6.3 V filament transformer. If the radio needs 110 V ac, use a 12.6 V filament transformer.

INITIAL POWER-UP CHECKS

With the right input ac voltage determined, it's time to gradually power up the radio. DO NOT plug it in and turn it on "to see if it works!" Applying full voltage to a radio that has not been used for a long time can destroy it! It's best to use a variable transformer such as a Variac and ramp up the voltage slowly, or use a "dim bulb tester" (a 100 W light-bulb wired in series with one leg of the ac power). Turn on the radio, and watch for any sparking, flashing, or a red glow from the plates of the rectifier tube, or smoke. If any of these occur, immediately remove power and correct the problem. Observe that the tube filaments should light (although you won't see the glow from metal tubes, you should be able to feel them warm up). Again, any tubes that fail to light should be replaced before you continue.

Now hook up a speaker and antenna, and test the radio. With any luck you'll be greeted by a perfectly performing radio. Seldom, however, is that the case. You may encounter any number of problems at this point. Dirty bandswitches and other controls manifest themselves by intermittently cutting out; they can be cleaned by DeoxIT contact cleaner applied with a cotton swab (don't spray the switch directly!). Scratchy volume or RF gain controls can be cleaned with some DeoxIT; in some cases you might need to remove the control and uncrimp the cover to reveal the carbon element inside.

If a receiver is totally dead at this point but the filaments and dial lights are lit, double-check to see that the Receive-Standby switch is in the receive position, and any battery plug or standby switch jumpers (as described in the manual) are in their correct place.

Although comprehensive troubleshooting is covered elsewhere in this chapter, the next step is comparing voltages with those stated in the user manual. If the manual doesn't have a voltage table denoting the expected voltage at each tube pin, expect 200-350 V at the tube plate terminals, a few volts at the cathode (unless it's directly grounded), 70-200 V at the screen, and slightly negative voltage at the grid. If you're faced with this situation and a newcomer to troubleshooting vintage gear, help can be found at **amfone.net**, **www.antiqueradios.com**, or other forums that cater to boat-anchors and/or vintage radio repair and restoration.

26.11.3 Alignment

Over the years hams have been cautioned that alignment is usually the *last* thing that should be attempted to repair a radio. In general this is true — but it's also a certainty that a 50-year-old radio *will* need alignment in order for it to perform at its best. In any case, replace the capacitors and any other faulty components before you attempt alignment — it'll never be right if it still has bad parts! You'll need a good signal generator and a volt-ohm-meter or oscilloscope. Follow the manufacturer's instructions, and with care you'll be rewarded with a radio that performs as good as it did when it was new.

RECEIVER ALIGNMENT

One last caution — alignment should not be attempted by the novice technician or if you do not have the proper equipment or experience. That said, alignment may be justified under the following conditions:

• The set is very old and has not been adjusted in many years.

• The circuit has been subject to abusive treatment or environment.

• There is obvious misalignment from a previous repair.

• Tuned-circuit components or crystals have been replaced.

• An inexperienced technician attempted alignment without proper equipment.

• There is a malfunction, but all other circuit conditions are normal. (Faulty transformers can be located because they will not tune.)

Even if one of the above conditions is met, do not attempt alignment unless you have the proper equipment. Receiver alignment should progress from the detector to the antenna terminals. When working on an FM receiver, align the detector first, then the IF and limiter stages and finally the RF amplifier and local oscillator stages. For an AM receiver, align the IF stages first, then the RF amplifier and oscillator stages.

Both AM and FM receivers can be aligned in much the same manner. Always follow the manufacturer's recommended alignment procedure. If one is not available, follow these guidelines:

1. Set the receiver RF gain to maximum, BFO control to zero or center (if applicable to your receiver), and tune to the high end of the receiver passband.
2. Disable the AGC.
3. Set the signal source to the center of the IF passband, with no modulation and minimum signal level.
4. Connect the signal source to the input of the IF section.
5. Connect a voltmeter to the IF output.
6. Adjust the signal-source level for a slight indication on the voltmeter.
7. Peak each IF transformer in order, from the meter to the signal source. The adjustments interact; repeat steps 6 and 7 until adjustment brings no noticeable improvement.
8. Remove the signal source from the IF section input, reduce the level to minimum,

set the frequency to that shown on the receiver dial, and connect the source to the antenna terminals. If necessary, tune around for the signal — if the local oscillator is not tracking, it may be off.

9. Adjust the signal level to give a slight reading on the voltmeter.

10. Adjust the trimmer capacitor of the RF amplifier for a peak reading of the test signal. (Verify that you are reading the correct signal by switching the source on and off.)

11. Reset the signal source and the receiver tuning for the low end of the passband.

12. Adjust the local-oscillator padder for peak reading.

13. Steps 8 through 11 interact, so repeat them until the results are as good as you can get them.

26.11.4 Using Vintage Receivers

Connect a speaker, preferably the same impedance as the output impedance of the receiver. Some receivers have a 600 Ω and 3.2- or 4 Ω output. An 8 Ω speaker is fine — connect it to the low impedance output. Do not operate the receiver without a speaker, however, as the audio output transformer could be damaged by high voltage transients with no load. Alternatively, plug in a pair of headphones, keeping in mind that old receivers usually have high impedance headphone outputs and new headphones are usually low impedance. They'll work fine, but the volume may be considerably lower with the newer headphones.

If you're going to use the receiver in conjunction with a transmitter, you need to be able to mute the receiver while you're transmitting — otherwise, you'll end up with copious feedback from the receiver. Most receivers have mute terminals — some mute with a closed switch, others mute on open. Figure out which method your receiver and transmitter use. You'll need a relay if the receiver mute arrangement doesn't match that of the transmitter.

Some receivers — such as the older Hammarlund Super Pros and pre-WWII Hallicrafters models — use the mute terminals to open the B+ when putting the receiver in standby mode. This is extremely dangerous with 300 V or so on exposed terminals! An easy modification will save you from an almost certain shock. Open up the receiver and remove the wires from the standby terminals. Solder them together and insulate the connection with electrical tape or a wire nut. Better, solder them to an unused, ungrounded terminal if there's one handy. Next, examine the RF gain control and notice that one terminal is probably grounded. Cut this wire and solder a 47 kΩ resistor between ground and the RF gain control terminal. Connect a pair of wires from the terminals of the mute connection across the 47 kΩ resistor just installed. Now, with the mute terminals open the RF gain is all the way down so the receiver is essentially muted. Short the terminals to receive. The voltage here is low and not dangerous.

Next, connect an antenna and antenna relay in the same manner and tune the bands. You'll find that the best fidelity from the receiver occurs at its maximum bandwidth. The crystal filter, if fitted, can help notch out heterodynes, as can tuning the receiver slightly higher or lower. The bandspread control can be used to fine tune. Now, just enjoy using your classic, vintage equipment!

26.11.5 Plastic Restoration

Sometimes an old radio has a meter lens or dial face that is badly damaged. If it is cracked, there isn't much you can do but find a replacement. If it is just scratched, you have a good chance at fully restoring it.

First, remove the meter lens from the meter movement if possible. Most just snap on. To avoid damaging the very delicate needle and meter movement, place it in a protected area and be sure metal filings cannot get to the movement's magnet.

Make sure the scratch hasn't gone all the way though the plastic to become a crack, although even a deep scratch can be buffed out. You will need various grades of wet/dry sandpaper. Obtain sheets of 320, 400 and 600 grit (600 is the finest). One sheet will last a long time. Cut a piece about ½ inch by 2 inches and fold it in half. Start with 320 and gently sand in *one* direction only, over the scratch. This is very tedious and will take a while before you sand away enough plastic to get through the scratch.

Once the scratch is removed, it is time to start reconditioning the plastic. Again sanding in one direction, use the 400 and finally the 600 to completely remove all traces of the earlier sanding scratches. The 600 should leave almost a powdered effect, but the plastic will still be hazy and opaque. Sand a little more with the 600 just to be sure all traces of any sanding scratches are gone completely.

To remove the haze you will need a polishing compound called Novus #2 (**www.novuspolish.com** or hobby stores) and another compound called Novus #1, which is a plastic shiner and static remover. This will be important to remove the static on the meter cases when you finish. Static causes the needle to react strangely and erratically.

Start with just a drop of NOVUS #2 and a soft cloth such as the disposable shop towels found at auto parts stores for polishing. Cut a 2 inch by 3 inch piece and start polishing. Continue for a long time and bit by bit the haze will disappear — you will be left with a perfectly clear lens.

FRONT PANEL RESTORATION

The most important part of a radio restoration, cosmetically, is the front panel. The case should also look good, but the front panel is the highlight of the radio and needs the most attention. Usually, paint on a radio from the '50s and '60s is well oxidized and there may be some fine scratches as well.

Scratches can be touched up by using enamel model car paint. Buy a bottle of gloss white, gloss black, and the color closest to the panel you have. Into a small paper cup put a drop or two of the stock color. Using the white or the black, stirring in a small drop at a time, lighten or darken the color until it most closely matches the panel. Use a model paint brush with the finest tip you can find to fill just the scratch and not get it on the rest of the paint. Remove excess with a Q-tip. Let it dry completely.

Remove the panel completely, if possible, or at least remove all the knobs. You will work on them individually later. If the panel was originally a gloss panel, you are in luck. If it is a wrinkle finish or flat, this technique might not work for you — those will be addressed later.

Use the Novus #2 compound to remove a few microns of paint — just the oxidized layer. Place a drop on the panel, and with a soft cloth or shop towel, start working the Novus into the paint. You just want to remove the oxidation, so don't rub too hard. Be careful when working on paint that is a second layer above a base paint. It can be very thin and removed with the Novus. After a small amount of gentle polishing, get another cloth or towel and wipe off the panel, which should appear just as it did when it came from the factory.

If your panel is a wrinkle finish, you cannot use the Novus. Use a gentle soapy type cleaner and careful brush the ridges and peaks of the finish to remove layers of dirt and smoke. Sometimes cleaners like 409 and Simple Green will work very well, but be cautious that it doesn't take off the lettering. Be very careful around the lettering. One way to work it in is with a plumber's acid brush with the bristles cut very short. The bristles will get down into the crevices of the wrinkle finish and clean it. Once the panel is clean, it can be shined up a bit with some WD-40. This also works very well on wrinkle finish cabinets. Just lightly brush it on and remove it with a rag. This can collect dust but gives a nice wet finish to the wrinkle finish paints.

KNOBS

Most knobs are plastic or have metal plates around the bottom. Use the Novus #2 to shine up the flat parts of the knob. Knobs with flutes on the sides are very tedious to clean, but look beautiful once restored. Take a fine pick and drag it down each flute to scrape out the accumulated dirt. Once cleaned, the Novus can be used to shine up the flutes as well. On knobs with metalized bases, the bases are also shined up with the Novus. Make sure you don't polish off any markings on the trim bases. Sometimes the knobs will have white or red lines in the tops. Those can be filled with model paint to restore them to full beauty.

HOLES IN FRONT PANELS

It may be most disconcerting to find someone has drilled a hole in the panel for one reason or another. Extra holes greatly devalue the rig because to properly restore it, you have to find a replacement panel. Panels with wrong holes can be salvaged with quite nice results by using JB Weld epoxy metal filler (**www.jbweld.com**).

First remove the panel. If the hole is a considerable distance from the other knobs, repairs can be done on the radio but it is not advised. You will need a special tape called Kapton tape. This is a high temperature polymide film tape that is widely available but not cheap. A little tape lasts a long time.

You will need a piece of tape slightly larger than the hole. Other types of tape may work but won't give as smooth a finish. If the panel is wrinkle finished, you may want a rough finish tape such as masking tape. The key is a tight fit to the front of the panel. Place a piece of tape across the hole on the front of the panel and seal it securely all around the hole.

Lay the panel on a flat surface tape-down so the tape will be held flat and not bulge at all. Mix a suitable amount of the JB Weld epoxy and flow it into the hole from the rear of the panel. Stir it while it is still very wet and pliable to make sure no air bubbles are in the hole. Let it cure securely overnight so the hole will be filled and rock hard.

Flip the panel over and remove the tape. If you have secured the tape well enough, none of the epoxy will have been drawn out onto the front surface. There should be a flat filled area exactly level with the rest of the panel.

Now you can touch up the repaired hole with an exact match of spray paint. Mask off the rest of the panel so you don't get any on the lettering. You can also use the model paint method, described for scratch repair. Once painted, the offending hole should be virtually invisible.

BROKEN PLASTIC

Sometimes a microphone or other item will have a chunk of the plastic broken out of it. It is most unsightly and usually is the reason for discarding the item. But, using our repair technology, it can be saved and fully restored as in this example of repairing a damaged microphone case. This procedure will work well on broken Bakelite cases too.

Once again, we will use JB Weld Epoxy and Kapton tape. Remove the microphone elements and switch from the case along with the cord and anything else not plastic. Clean the area around the broken part well. With the Kapton tape, make a backing area on the inside of the case to form a backing for the epoxy. The tape will hold it well and not deform.

Mix some JB Weld and pour it into the space around the break. Fill *higher* than the surrounding plastic. This will be difficult as the fill area will not be level. It may take a couple of fills to build up the area past the level of the surrounding plastic. Once cured and very hard (wait at least 24 hours), you now can begin to file the epoxy. File it down until it is nearly level with the plastic and then switch to sandpaper. Carefully sand the epoxy so it is exactly flush with the original plastic, and make sure the shape is correct. You can always add more JB Weld if too much is filed off.

Once sanded flush, finish the sanding with fine sandpaper (400 and 600 grade). The JB Weld will shine just like the original plastic, but will be the wrong color. Spray paint the entire case with a color close to the original. Once painted, the repair will be virtually undetectable!

26.12 References

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