By H. Ward Silver, NØAX

Amplifier Care and Maintenance

With few moving parts, your amplifier can be easy to overlook. Here are some ideas for taking care of amplifiers.

Amplifiers come in all shapes and sizes, large and small, light or heavy, tube or solid-state, VHF or HF. Regardless, they all need a little TLC from time to time. They can cost as much as top-of-the-line radios, so it's important that they get a little maintenance on a regular basis.

While this article focuses on amplifiers that use vacuum tubes, many of the ideas presented here can and should be applied to any amateur amplifier—HF or VHF/UHF. Solid-state amplifiers operate at lower voltages and generally have fewer points of failure, but they still need occasional maintenance.

Safety First

It is important to review good safety practices.[1] Tube amplifiers use power supply voltages well in excess of 1 kV and the RF output at full throttle can be hundreds of volts, as well. Almost every voltage in an 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 or "rig" 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 won't give current a chance 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 milliampere levels—don't tempt the laws of physics.
- *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.
- *A Chicken Stick*—Make this simple safety accessory shown in Figure 1 and use it whenever you work on equipment in which hazardous voltages have been present. The ground wire should be heavy duty (12 gauge minimum) 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*—It's always a good idea to 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 can be nearby in case of trouble. Your buddy should know how to remove power and administer basic first aid. Since hams work around electrical equipment frequently, it would be a good idea to have your buddy or someone in the household know CPR, as well.[2]

Cleanliness

The first rule of taking good care of an amplifier is cleanliness. I realize that 90 percent of ham shacks have just failed the first rule. Amplifiers need not be kept sparkling new, but their worst enemy is heat. Excess heat accelerates component aging and stresses those expensive tubes and transformers. There are two areas to keep clean—the inside and the outside.

Outside the amplifier, you need to prevent dust and obstructions from blocking the paths by which heat is removed. This means keeping all ventilation holes free of the ever-present dust bunnies, pet hair

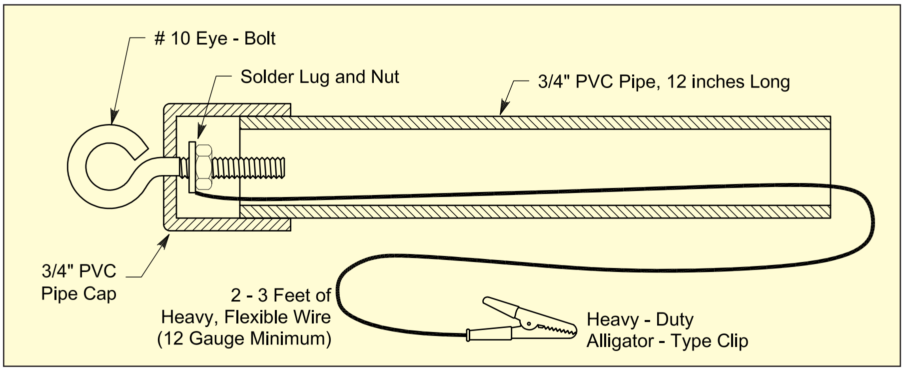

Figure 1—The "chicken stick" is a great way to ensure that everything inside the amplifier that should be discharged actually is. It can be a life saver.

[1]Notes appear on page 37.

and insects. Fan intakes are particularly susceptible to inhaling all sorts of "goop." Get out the vacuum cleaner and clean not only the amplifier, but the surrounding areas. Don't even think about letting liquids anywhere near the amplifier. One spilled cup of coffee can cause hundreds of dollars of damage.

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.

Just as the outside needs to be kept clean, so does the inside. High voltage (HV) circuits attract dust like crazy. The dust slows heat dissipation and will eventually build up to the point where it arcs or carbonizes. Our friend the vacuum cleaner should make another appearance 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 visitors. While you're cleaning the inside, this is a great time to perform a visual inspection as described in the next section.

Vacuuming works best with an attachment commonly known as a "crevice cleaner." Figure 2 shows a crevice cleaning attachment being used with a small paintbrush to dislodge and remove dust. 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. Besides, that dust you blow all over is going to wind up in some other equipment, so it's best to take it out of circulation, so to speak. The brush will root dust out of tight places and off components without damaging them or pulling on connecting wires.

If you can't get a brush or attachment close enough, a spray can of compressed air will usually dislodge dust and dirt. 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 unless the manufacturer advises doing so—you might leave behind a residue or damage the component.

Visual Inspection

Once the amplifier has been cleaned, it's time for a visual inspection. Remove any internal covers or access panels and...*stop*! Get out the chicken stick, 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. Amplifiers have far fewer components than transceivers do, so it's quite feasible to 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. While you're in there, does anything smell burnt? The nose can quickly detect the odors of toasted transformer, cooked capacitor or roasted resistor. Learn the smells of healthy and not-so-healthy components.

Make a note of what you find, repair, or replace—even if it's absolutely nothing. If you don't keep a shack notebook, start one. A simple spiral notebook with notes about maintenance, wiring, color coding, antenna behavior and so forth can be a big time-saver.

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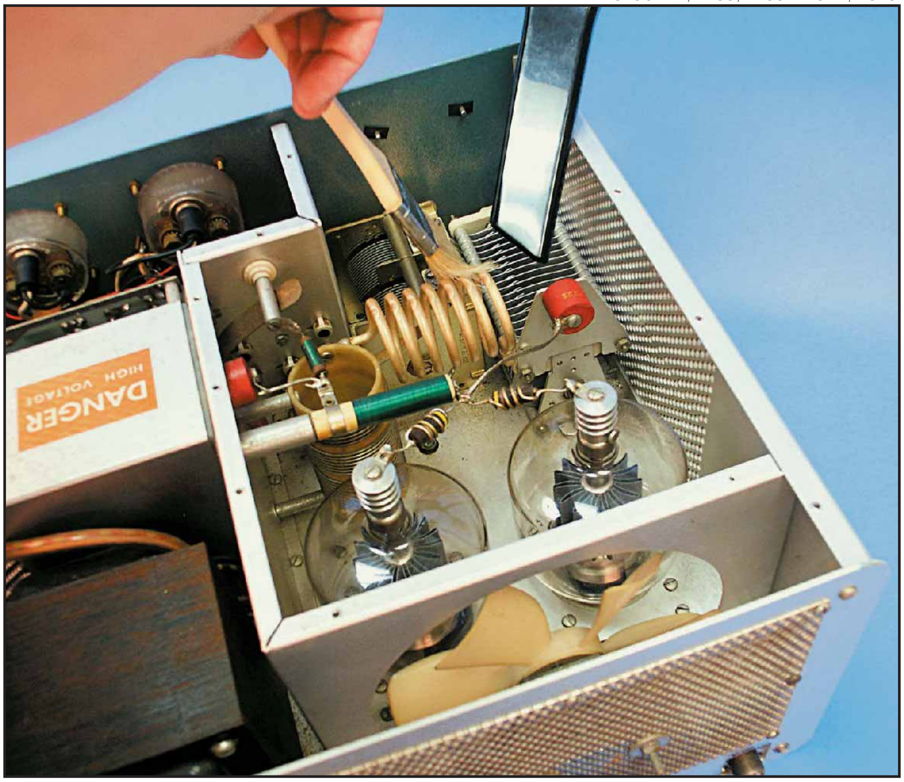

Figure 2—A small paintbrush and a vacuum cleaner crevice attachment make dust removal easy.

Electrical Components

An amplifier contains many heavy-duty HV and RF components. These can be expensive and hard to replace, so it's important that you take good care of them. 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. Transformers need little maintenance except to be kept cool and be mounted securely. Line components such as switches, circuit breakers and fuses, if mechanically sound and adequately rated, are usually electrically okay, as well.

Rectifiers and the capacitors that filter the HV dc 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.

Located at the output of the filter, 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.

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, as the author points out later. 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.—*Ed*.] If visual inspection shows heavy pitting or discoloration or resistance measurements show the relay to have intermittent contact quality, it is best replaced.

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.

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 under clamps or tie-downs. It's a good idea to 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 that have RF decks that are in separate enclosures from those of their power supplies. 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 both the soldered electrical integrity and the mechanical stability of those cables and make sure they are tightly fastened.

As with relays, switches found in amplifiers are either control function orientated or RF routers. Adequately rated control switches, if mechanically sound, are usually okay. Bandswitches 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 3 is a photo of 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 pink pencil eraser, but plating can be easily removed, so use caution with this method and be sure to remove any eraser crumbs. Rotary switch contacts cannot be replaced easily although individual wafer sections may be replaced if an exact matching part can be obtained.

Amplifiers use all types of capacitors and resistors. When replacing them, be sure to use a part rated for the use to which it will be put. Voltage and power-handling ratings are particularly important, especially of those 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.

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 and Surplus Sales of Nebraska are familiar names.[3] Hamfests and Web sites such as **www.eham.net** or **www.k1dwu.net/hamtrader** often have amplifier components for sale. You might consider buying another amplifier of the same type in non-working condition for parts use.

Tubes

The single most expensive component in an amplifier is usually the vacuum tube that performs the amplification. Good maintenance of tubes 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 current to be sure that the tubes are being operated properly and giving you maximum lifetime. Penta Labs has an excellent Web page on maintaining power tubes.[4]

The internal mechanical structures of tubes generally do not deal well with mechanical shock and vibration, so be gentle. 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 warp-

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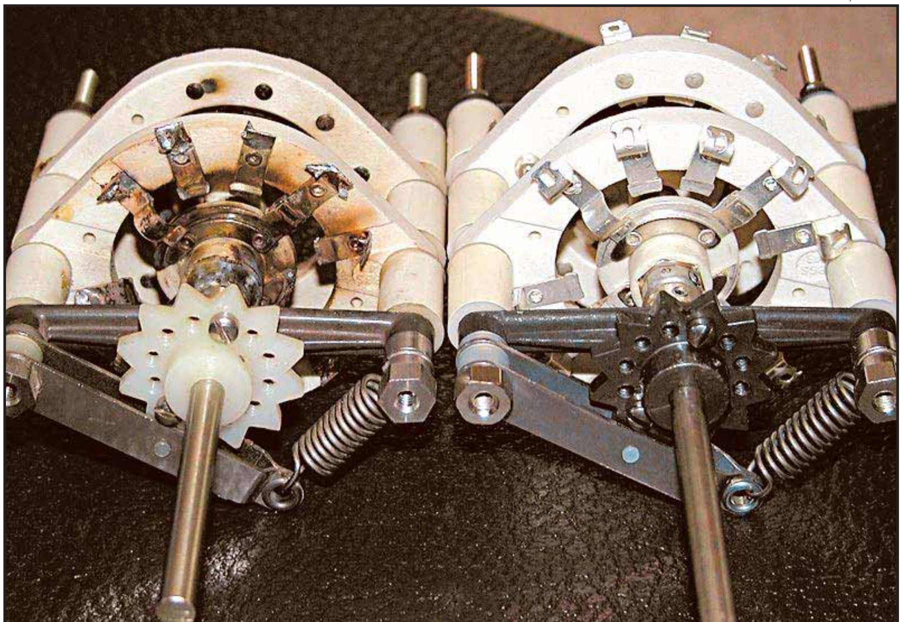

Figure 3—The band switch section on the left clearly shows the signs of destructive arcing.

ing 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.

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, 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. This is perfect information for the shack notebook. Record tuning settings, drive levels, and tube voltages and currents on each band and with every antenna. When things change, you can refer back to the notebook instead of relying on memory.

Mechanical

While the amplifier is primarily an electronic beast, it has a significant number of mechanical parts that affect its well-being. Thermal cycling and heat-related stresses can result in mechanical connections loosening over time or material failures.

Switch shafts, shaft couplings 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 that are mounted with a single nut in a round panel hole are notorious for loosening with repeated connect/disconnections.

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

A great time to clean the front and back panels and get gummy finger deposits off before they cause permanent finish damage is during maintenance. If the amplifier is missing a foot on the cabinet or an internal shock mount, replace it. A clean unit with a complete cabinet will have a significantly higher resale value than a dirty, grubby one, so it's in your interest to keep the equipment looking its best.

Shipping

When you are traveling with an amplifier or shipping it, some care in packing will prevent needless 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.[5]

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

This discussion should have given you plenty to think about. It's easy to defer maintenance, but as with a vehicle, performance and lifetime are improved if a regular program is put into place. For amateur use, there is little need for maintenance more frequently than once per year. If there is a period of the year in which you are most active, put a note on the calendar about six weeks in advance to "open the hood," giving you time to obtain and replace any components.

Consider the maintenance requirements of your amplifier and what its manufacturer recommends. Sit down with your amplifier's manuals and make up a checklist of what major steps and tools are required. When maintenance time rolls around, you'll be prepared and be able to perform the job in the most efficient manner.

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. Figure 4 shows a moderately-high-level troubleshooting flow chart. 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, of course.

You might be surprised how 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. Assuming that ac power is present, trace through any internal fuses, interlocks and relays all the way through to the transformer primary terminals.

Hard failures in a high voltage power supply are rarely subtle, so it's usually clear if there is a problem and what components are involved. 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 DVM diode checker. An open rectifier will result in a drop in the HV output of 50 percent 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 compo-

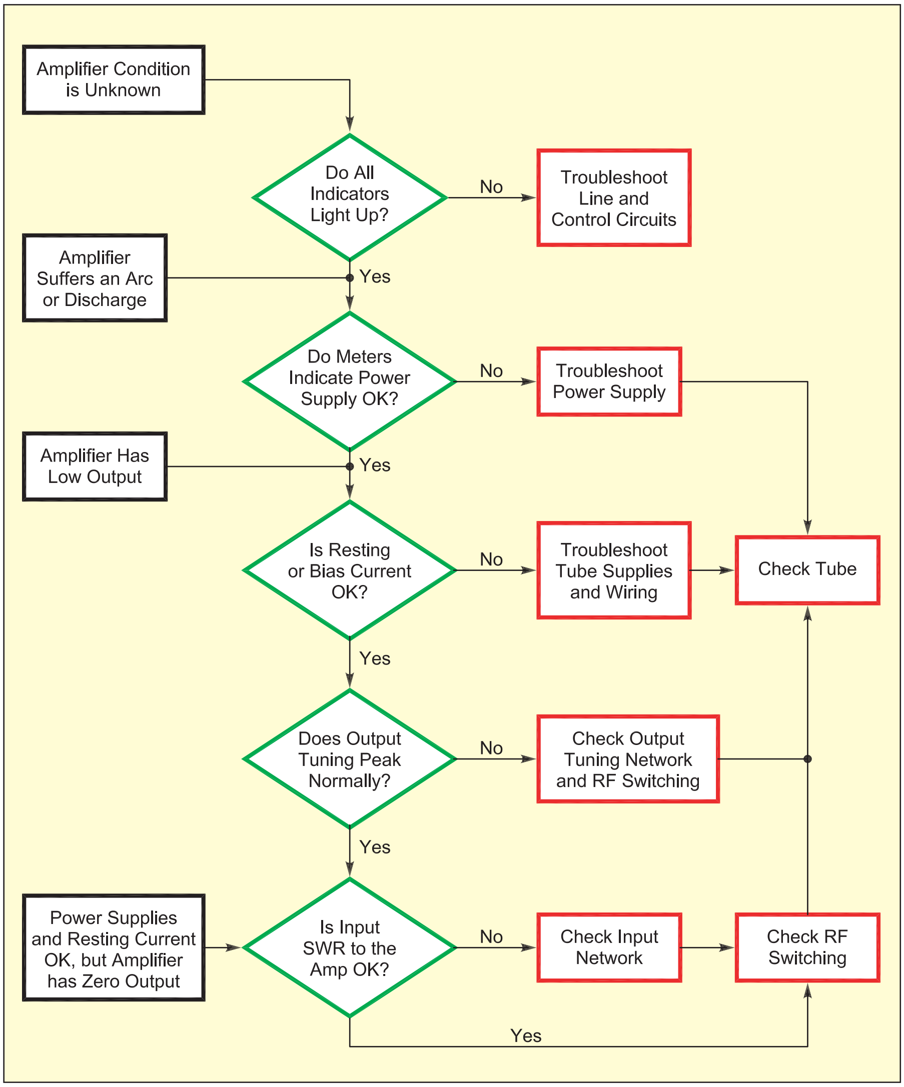

Figure 4—This moderate-level flow chart is a good way to identify amplifier problems quickly in lieu of a misplaced or nonexistent manufacturer's troubleshooting procedure.

nents—they may have been damaged by the current surge caused by a shorted filter. Power transformer failures usually manifest themselves by insulation failures with consequent arcing of the windings. Either can result in the unmistakable aroma of overheated transformer. A failed transformer is generally not repairable.

Along with the HV plate supply, tetrode screen supplies occasionally fail, too. 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 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.

Having exhausted power supply and dc problems, you will then turn to the RF components or "RF deck." There is a natural tendency to forge ahead and swap in a known-good tube or tubes. Don't! Tubes are expensive and if the problem is elsewhere, you may damage the spares. Wait to swap tubes until you are sure that the tube is likely to be defective.

Check the input SWR to the amplifier. If it has changed (you did write down the normal SWR and drive levels, didn't you?) then you likely have a problem in the input circuitry or one or more tubes have failed. Perform a visual check of the input circuitry and the band switch, followed by an ohmmeter check of all input components.

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.

The key to finding the trouble with your amplifier 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 are very simple and can be isolated by careful, step-by-step tests.

Summary

Amplifiers have been part of ham radio for many years. They are simple, reliable pieces of equipment that respond well to basic care and common sense. Take the time to know your amp—inside and out. If you take care of it, it will reward you with reliable service and maximum tube lifetime.

Notes

[1]Chapter 9 of the current *ARRL Handbook for Radio Communications* is an excellent source of safety information. Available from your local dealer or the ARRL Bookstore. Order no. 1921 (softcover), no. 1948 (hardcover). Telephone toll-free in the US 888-277-5289, or 860-594-0355, fax 860-594-0303; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[2]Instructions for CPR can be found at: **about-the-web.com/spiritworks/web/Kaiser/html/adult.htm**.

[3]Two sources of HV and RF parts include Surplus Sales of Nebraska (**www.surplussales.com**) and Fair Radio Sales (**www.fairradio.com**). Others can be found at the ARRL Technical Information Service database (**www.arrl.org/tis/tisfind.html**).

[4]Penta Labs, "Tube Maintenance & Education" (**www.pentalaboratories.com/maintenance.asp**).

[5]Pelican (**www.pelican-shipping-cases.com**) and Anvil (**www.anvilsite.com**) make excellent shipping cases suitable for carrying amplifiers and radio equipment.

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Building a Modern Signal Tracer

Add this versatile tool to your test bench and hear what you've been missing.

Curt Terwilliger, W6XJ

A few years ago I was developing a speech compressor/clipper, and needed to test its audio quality. That's when I realized that something was missing from my workbench. If you want to measure voltage or current, a multimeter works fine. If you have a scope, you can see waveforms displayed graphically. But if you want to make a subjective measurement — such as audio quality — those tools aren't enough.

I wanted to know how my speech processor output sounded, not how it looked. Did it have hum on the output? Did it make the microphone sound tinny or add too much distortion? Meters and a scope weren't very helpful — I needed an easy way to make signals audible. In short, I needed a *signal tracer*.

Signal Tracing

A signal tracer is basically an audio amplifier and speaker, with a very high, but adjustable, gain. The name comes from its original application — tracking a test signal from one stage to the next in a defective receiver. With its high gain and the help of a "detector probe," the signal tracer could hear even some radio frequency signals at the first stage of a receiver. By tracing from stage to stage until the signals vanished, you could quickly determine where the problem lay.

In days gone by, signal tracers were popular kits available from Heath, Knight, Eico and the like.[1] While not quite boat anchors, they were nevertheless heavy, bulky and power hungry by today's standards. They also offered some features that are not useful today — such as the ability to apply 100 V or more to a suspect circuit. In the old days, that might have been a good way to check for noisy parts or solder joints. With modern solid state rigs, though, that is just a good way to generate smoke. So rather than pick up an old signal tracer at a hamfest or auction site, I decided to build a modern version. Table 1 gives a summary of goals for my design.

Design Overview

The core of my design is a low noise amplification block with switchable gain of 1, 10, 100 or 1000. In front of this is a selectable 40 dB attenuator, to prevent overloading on large input signals. In addition, there needs to be a selectable detector to allow tracing RF and IF signals in a receiver. Following the amplification block is a VOLUME control, and a 1 W power amplifier driving a small speaker.

Older instruments usually had just one input connector. I didn't find this convenient if I wanted to switch from, say, a test probe with a BNC connector to a shielded cable with an RCA plug. No one likes to be hunting for adapter plugs all the time. So my design has a BNC jack that accepts a 'scope probe, a phono jack that accepts an ordinary audio cable and a mini phone jack that accepts a stereo plug from a computer sound card or other source. Oh yes, there's also a second BNC jack on the rear panel. More on that shortly.

For convenience, there are also two output connections for headphones — accepting either ⅛ or ¼ inch plugs. So no adapter plugs are needed here, either.

Table 1
Design Goals

- Amplification range to 4000 times
- High input impedance (1 MΩ)
- Full audio bandwidth response
- Low internal noise and distortion
- Built-in RF detector
- Versatile input selection
- Speaker or headphone output

Input Section

As you can see in Figure 1, the front panel inputs are wired in parallel. The mini phone jack is wired to accept stereo signals — the two channels are mixed with a resistor network. If you insert a mono plug, the signal will make it through, but its amplitude will be cut in half.

A blocking capacitor, C3, keeps dc away from the active circuits. But you shouldn't trace circuits where more than 150 V is present.

I mentioned that there is a second BNC input on the rear panel. This goes to the "vertical amplification output" of my oscilloscope. If this BNC input is selected, I can

Hamspeak

BNC — RF coaxial connector with good performance through the UHF region. It is of a size convenient to smaller coax cables such as RG-58, 59 or 8X and features a twist lock bayonet attached back shell.

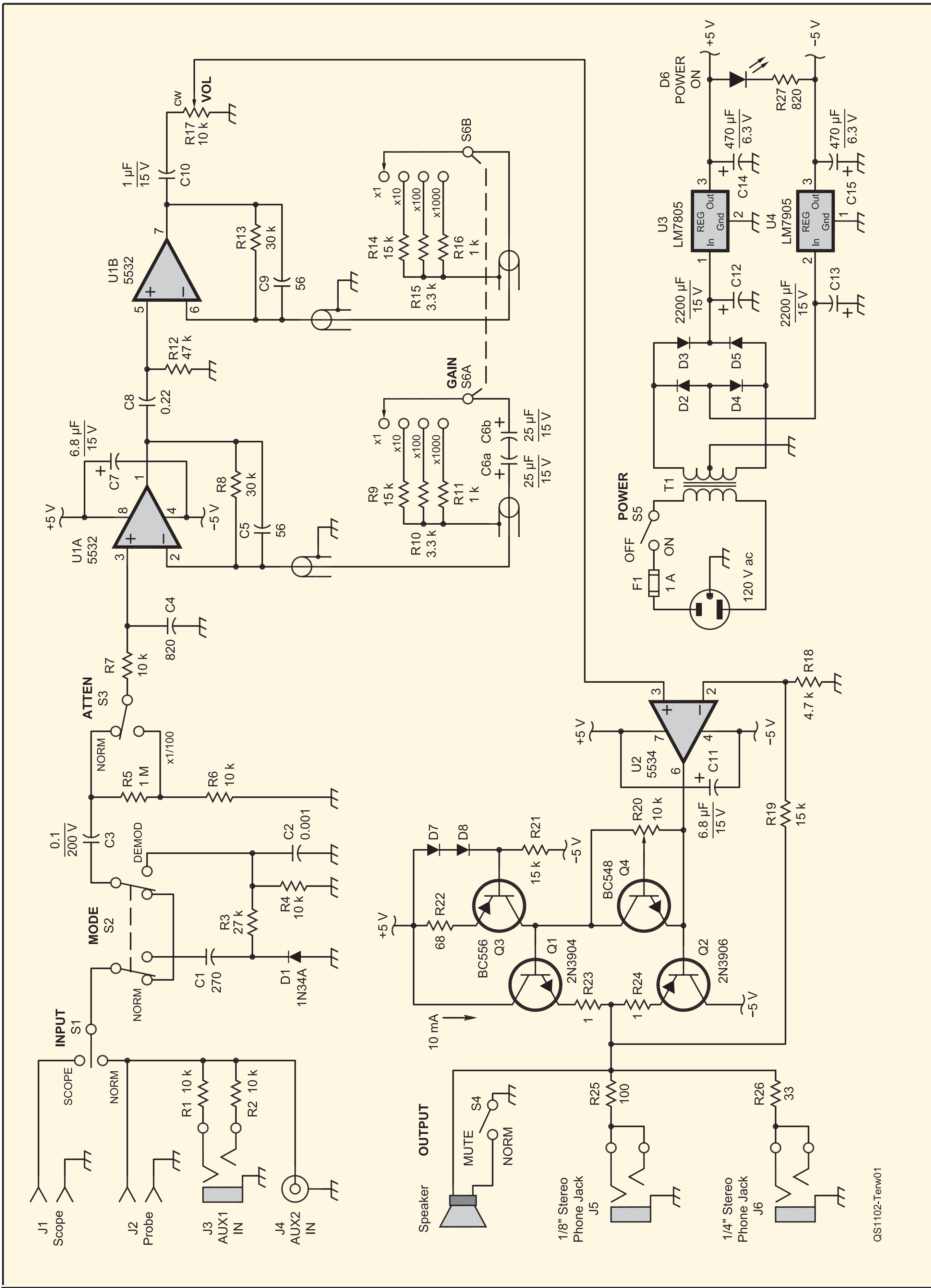
CTCSS — Abbreviation for continuous tone-controlled squelch system, a series of subaudible tones that some repeaters use to restrict access.

Dead bug — Term for an electronic circuit construction technique in which components are placed on a circuit board with their leads up and then wired with point-to-point wiring. The name comes from the appearance of multilead integrated circuits, which look reminiscent of expired insects with their legs up.

Operational Amplifier (op-amp) — Integrated circuit that contains a symmetrical circuit of transistors and resistors with highly improved characteristics over other forms of analog amplifiers.

Wall wart — Small power supply unit for low power equipment with integral plug for standard ac wall socket. Colloquially named due to its appearance as a protrusion from a wall socket.

[1]Notes appear on page 44.


J1
Scope
J2
Probe
J3
AUX1
IN
J4
AUX2
IN
SCOPE
NORM
INPUT
S1
R1 10 k
R2 10 k
MODE
S2
NORM
DEMOD
C1
270
D1
1N34A
R3
27 k
R4
10 k
C2
0.001
0.1
200 V
C3
R5
1 M
R6
10 k
NORM
x1/100
ATTEN
S3
R7
10 k
C4
820
U1A
5532
+5 V
−5 V
C7
6.8 µF
15 V
C8
0.22
R8
30 k
C5
56
R12
47 k
U1B
5532
R13
30 k
C9
56
C10
1 µF
15 V
R17
10 k
cw
VOL
GAIN
S6A
S6B
x1
x10
x100
x1000
R9
15 k
R10
3.3 k
R11
1 k
R14
15 k
R15
3.3 k
R16
1 k
C6a
C6b
25 µF
15 V
D6
POWER
ON
R27
820
C14
470 µF
6.3 V
C15
470 µF
6.3 V
U3
LM7805
U4
LM7905
REG
In
Gnd
Out
C12
2200 µF
15 V
C13
2200 µF
15 V
D2
D3
D4
D5
T1
POWER
S5
OFF
ON
F1
1 A
120 V ac
U2
5534
C11
6.8 µF
15 V
R18
4.7 k
R19
15 k
R20
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R21
15 k
D7
D8
R22
68
Q3
BC556
Q4
BC548
Q1
2N3904
Q2
2N3906
R23
1
R24
1
10 mA
OUTPUT
Speaker
MUTE
NORM
S4
R25
100
R26
33
1/8" Stereo
Phone Jack
J5
1/4" Stereo
Phone Jack
J6
QS1102-Terw01

Figure 1—Schematic diagram and parts list for the signal tracer. All capacitors 15 V or greater unless otherwise specified; all resistors ¼ watt, 5%.

C1 — 270 pF ceramic capacitor.
C2 — 0.001 µF ceramic capacitor.
C3 — 0.1 µF, 200 V film capacitor.
C4 — 820 pF ceramic capacitor.
C5, C9 — 56 pF ceramic capacitor.
C6a, C6b — 25 µF electrolytic capacitor.
C7, C11 — 6.8 µF electrolytic capacitor.
C8 — 0.22 µF ceramic capacitor.
C10 — 1 µF film capacitor.
C12, C13 — 2200 µF electrolytic capacitor.
C14, C15 — 470 µF, 6.3 V electrolytic capacitor.
D1 — 1N34A germanium diode (Mouser 833-1N34A-TP).
D2-D5 — 1N4001 (Mouser 512-1N4001).
D6 — LED
D7, D8 — 1N4148A silicon diode (Mouser 512-1N4148).
F1 — 1 A in-line fuse.
J1, J2 — BNC jack.
J3, J5 — ⅛ inch stereo phone jack.
J4 — Phono jack.
J6 — ¼ inch stereo phone jack.
Q1 — 2N3904 transistor (Mouser 863-2N3904G).
Q2 — 2N3906 transistor (Mouser 863-2N3906G).
Q3 — BC556 transistor (Mouser 512-BC556).
Q4 — BC548 transistor (Mouser 512-BC548A).
R1, R2, R4, R6, R7 — 10 kΩ resistor.
R3 — 27 kΩ resistor.
R5 — 1 MΩ resistor.
R8, R13 — 30 kΩ resistor.
R9, R14, R19, R21 — 15 kΩ resistor.
R10, R15 — 3.3 kΩ resistor.
R11, R16 — 1 kΩ resistor.
R12 — 47 kΩ resistor.
R17 — 10 kΩ audio taper potentiometer.
R18 — 4.7 kΩ resistor.
R20 — 10 kΩ linear taper trimpot.
R22 — 68 Ω resistor.
R23, R24 — 1 Ω resistor.
R25 — 100 Ω resistor.
R26 — 33 Ω resistor.
R27 — 820 Ω resistor.
S1, S3 — SPDT toggle switch.
S2 — DPDT toggle switch.
S4, S5 — SPST toggle switch.
S6 — 2 pole, 4 position rotary switch.
SP — Speaker, 8 Ω, 1 W.
T1 — Transformer, 12.6 V, 1 A center tapped.
U1 — 5532 IC (Mouser 512-NE5532N).
U2 — 5534 IC.
U3 — LM7805 IC (Mouser 512-LM7805ACT).
U4 — LM7905 IC (Mouser 512-LM7905CT).

Figure 2 — Signal tracer front panel. The legend was designed using Microsoft *PowerPoint*.

Figure 3 — Signal tracer rear panel. This legend was also prepared on clear film using Microsoft *PowerPoint*.

listen to the waveform that the scope is displaying.[2] It's a convenient way to have the scope probe do double duty providing simultaneous audio and video.

The Detector

The RF detector is a simple rectifier — your basic crystal set. I used the traditional 1N34A germanium diode, but you could substitute a Schottky diode such as the 1N5711, or even a general purpose switching diode like the 1N4148A.[3]

If you plan to use the signal tracer to trace RF signals in a high impedance environment (such as in a vacuum tube set), you might find that this built-in detector loads the circuit too much due to cable capacitance. In that case, you could build an outboard detector, such as the RF probe shown in *The ARRL Handbook* for so many years.[4]

Low Noise Amplifier

The low noise amplifier module is built around the venerable but still hard-to-beat 553X series of low noise operational amplifiers. The variable gain part of the circuit is made from a 5532 dual section op-amp. Each section forms an amplifier with switch-selected gain of 1, 3, 10 or 31. Changing resistors in the feedback loop controls the gain. Since the two sections are in series, and the switches are ganged, the stage gains multiply, giving an overall gain of approximately 1, 10, 100 or 1000.

Limiting the gain of a single stage to 31 or less has several advantages: it makes self-oscillation less likely, it reduces the dc offset at the output and it ensures that the op-amp doesn't run out of steam at high frequencies because high gain takes its toll on the gain-bandwidth product of the chip.

The input has a 1 MΩ resistance. While this makes for a nice high impedance input, it also causes a dc offset problem in the first stage. The input bias current of the op-amp (up to 800 nA) flowing through 1 MΩ creates an offset voltage of several hundred millivolts. Clearly, you don't want to then amplify that by 31, or even 10 — the output will hit the power supply rail. So the first stage uses capacitors, C6a and C6b, to lift the feedback leg above ground and limit the dc gain to 1.

The second stage is ac coupled to the first stage, so it doesn't try to amplify whatever dc offset remains. While we don't have to worry about the second stage output offset hitting the output rail, it can still be significant (nearly 1 V). So its output is ac coupled to the power amplifier to prevent dc from being sent to the speaker.

Both op-amp stages were tamed with 56 pF capacitors between their respective outputs and inverting inputs. These were needed in order to kill a high frequency oscillation that showed up in the prototype when gains of 10 or greater were selected.

The Output Amplifier

The usual choice for a small audio power amplifier would be the LM386 chip. I've never liked them — they sound harsh to my ears. A few years ago I stumbled across the excellent Web site of XQ6FOD, who shares my feelings about the 386.[5] He designed several low power, discrete amps that are great substitutes for the 386. I lifted one of his circuits, and found that it made an outstanding amplifier. It contributes an additional gain of 4, while adding very little noise or distortion, one of my key objectives.

A 5534 single-section op-amp is used to drive a complementary set of output transistors, Q1 and Q2. Those are biased by a V_{BE}

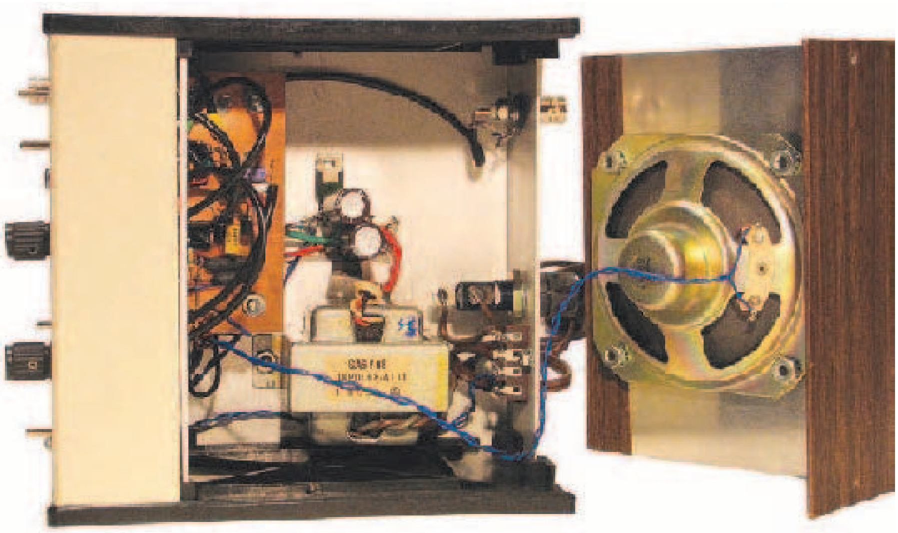


Figure 4 — View of the circuit using dead bug style of construction on a piece of copper clad board. The wiring method is not critical — just avoid ground loops.

(voltage between transistor base and emitter) multiplier, Q4, driven by a current source, Q3. Just set the trimpot for about 10 mA of idle current in the output transistors and you are good to go.

Why go to so much trouble to get high quality audio for this simple signal tracer, you might ask. Well, you want to know for sure that any noise or distortion you hear is due to the signal under examination — not an artifact introduced by the test rig. Otherwise, you couldn't use this signal tracer to work on high quality audio circuits.[6]

Speakers and Headphones

The internal speaker is adequate for many tasks. But it is not big enough to reproduce low frequencies, including power line hum or CTCSS tones. For such tasks, you will want to use high fidelity headphones. I put in jacks for both standard and mini phone plugs. Since all modern phones are wired for stereo, so are the jacks. I adjusted the size of the series resistors so the sound level was about the same whether I used the speaker, a large set of phones on the big jack, or a set of ear buds on the mini jack. A switch disconnects the speaker for headphone-only use.

Power Supply

I decided to use a conventional transformer rather than a wall wart. I don't like the constant current drain of wall warts, so I wanted to be able to switch off power completely. That meant an internal transformer, with fuse and power switch. A shielded power transformer helps prevent magnetically coupled hum. Mine was liberated from an old CD player, but they are widely available from electronics suppliers.

Construction Tips

I built this unit in a Ten-Tec enclosure that had been bouncing around in my junk box for a few years — you can see a few scuff marks in the photos. It has an aluminum half frame, surrounded by plastic end panels. You might want to find a full metal enclosure if you want to minimize RF interference.

The front panel legend (see Figure 2) was designed using Microsoft *PowerPoint*, then printed on a transparent sheet. That sheet was then cut to size, holes punched for the connectors and controls, and it was then glued to the front panel. A similar technique was used for the rear panel (see Figure 3).

Wiring style is not critical. I used the dead bug style of construction on a piece of copper clad board, as shown in Figure 4. Do take care to avoid ground loops. Make sure all the input and output connectors are isolated from the metal panel, then connect their ground tabs with separate wires to a central grounding point in the power supply.

Applications

The original use for this signal tracer was analyzing noise and distortion in my speech processor. In another project, I used it to listen to white noise generated by various voltage regulators. Did you know that Zener diodes are sometimes noisier than three terminal regulators (unless you bias the Zener heavily)? I had no idea about that until the signal tracer revealed the truth.

I've also used this tracer to find an open connection in my living room audio setup, to test radio headphone outputs and to listen for dial tones while tracing telephone wiring problems.

Some of the classic literature on signal tracing that can be found online offers useful tips.[7] For instance: many amplifiers use an electrolytic bypass capacitor across the emitter (or cathode) bias resistor — and these sometimes dry out and lose capacitance with age. If you suspect that has happened, try listening to the signal at the top of the capacitor. You should hear little or nothing if the bypass cap is doing its job. But if the cap is no good, you'll hear plenty of unwanted signal. Neat trick, eh?

Conclusion

Yogi Berra once said: "You can observe a lot just by watching." To that we might add: "And you can hear a lot just by listening." It's nice to have a set of ears on the test bench. After I finished this project, my only regret was that I hadn't built it long ago.

Notes

[1]See, for example, the old signal tracers pictured at **oak.cats.ohiou.edu/~postr/bapix/SigTrac2.htm**.

[2]The vertical amplification output is also useful when fed to a frequency counter, which then can show the frequency of the waveform under observation. In my shack, I leave a counter and the signal tracer permanently connected to the scope.

[3]J. Smith, K8ZOA, published a nice comparison of diode types used in RF detectors. See **www.cliftonlaboratories.com/diodes_for_rf_probes.htm**.

[4]*The ARRL Handbook for Radio Communications,* 2011 Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 0953 (Hardcover 0960). Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[5]Manfred's article at **ludens.cl/Electron/audioamps/AudioAmps.html** gives a very readable discussion of the issues with the LM386.

[6]For those who think this output amplifier is overkill, a simpler version with about half the parts is provided on **www.arrl.org/qst-in-depth**.

[7]Such as "Principles of Signal Tracing," reproduced from *Radio News*, Nov 1944, available on-line at **www.nostalgiaair.org/references/Articles/post/post01.htm**.

ARRL member and Amateur Extra class operator Curt Terwilliger, W6XJ, has been a homebrewer since he was first licensed at age 13. Among his favorite ham related milestones — receiving a Science Fair prize ribbon in high school for a balanced modulator speech clipper for his Johnson Ranger transmitter — and building a slow scan television receiver for an engineering lab course in college.

Before embarking on a technology career in California's Silicon Valley, Curt wrote an article for QST *on computer control of an ICOM radio. Published in 1981, it ran with the editor's prophetic subheading* "Ready for the computer age in Amateur Radio? It won't be long before many hams tie their computers to their radios. Here is an example of what we all may be doing one of these days." *Curt can be reached at 372 Darrell Rd, Hillsborough, CA 94010, or at* **qstdew6xj@gmail.com**.

Diode and Transistor Test Circuits

By Ed Hare, W1RFI

Editor's note: Section and figure references in this article are from the 2013 edition of the ARRL Handbook.

Testing diodes and transistors can easily be done as shown here with an analog VOM (volt-ohm-meter) for general quality. In addition, more involved tests for leakage, gain, and other parameters can also be done with the simple circuits in this article. These circuits can also be used for sorting and matching components which is often important for precision circuits.

Diode Tests

Diodes should be tested out of circuit. Disconnect one lead of the diode from the circuit, then measure the forward and reverse resistance. Diode quality is shown by the ratio of reverse to forward resistance. A ratio of 100:1 or greater is common for signal diodes. The ratio may go as low as 10:1 for old power diodes.

Using a VOM or multimeter set on the lowest scale for which resistance does not exceed full-scale, a good silicon diode will show 200 to 300 Ω of forward resistance and 200 to 400 Ω for a good germanium diode. The exact value can vary quite a bit from one meter to the next.

Next, test the reverse resistance. Reverse the lead polarity and set the meter to the highest resistance scale to measure diode reverse resistance. Good diodes should show 100 to 1000 MΩ of reverse resistance for silicon and 100 kΩ to 1 MΩ for germanium.

The preceding procedure measures the junction resistances at low voltage. It is not useful to test Zener diodes. A good Zener diode will not conduct in the reverse direction at voltages below its rating.

We can also test diodes by measuring the voltage drop across the diode junction while the diode is conducting. This is the test performed by a multimeter's diode junction test function. Silicon junctions usually show about 0.6 V at typical meter test levels, while germanium is typically 0.2 V. Junction voltage-drop increases with current flow. The circuit in **Figure 26.27** can be used to match diodes with respect to forward resistance at a given current level.

A final simple diode test measures leakage current. Place the diode in the circuit described above, but with reverse polarity. Set the specified reverse voltage and read the leakage current on a milliammeter. (The currents and voltages measured in the junction voltage-drop and leakage tests vary by several orders of magnitude.)

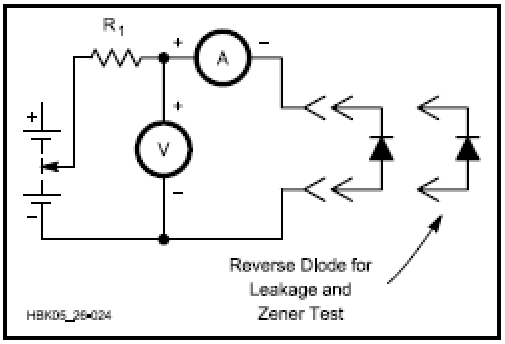


Figure 26.27 — A diode conduction, leakage and Zener-point test fixture. The ammeter should read mA for conduction and Zener point, µA for leakage tests.

The most important specification of a Zener diode is the Zener (or avalanche) voltage. The Zener-voltage test also uses the circuit of Figure 26.27. Connect the diode with reverse polarity. Set the voltage to minimum, then gradually increase it. You should read low current in the reverse mode, until the Zener point is reached. Once the device begins to conduct in the reverse direction, the current should increase dramatically. The voltage shown on the voltmeter is the Zener point of the diode. If a Zener diode has become leaky, it might show in the leakage-current measurement, but substitution is the only dependable test.

Bipolar Transistor Tests

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.

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 **Analog Basics** chapter for definitions of these and other transistor parameters.)

A suitable test fixture for base-collector leakage measurements is shown in **Figure 26.29**. Make the required connections and set the voltage as stated in the transistor specifications and compare the measured leakage current with that specified. Small-signal germanium transistors exhibit I_{cbo} and I_{ebo} leakage currents of about 15 µA. Leakage increases to 90 µA or more in high-power components. Leakage currents for silicon transistors are seldom more than 1 µA. Leakage current tends to double for every 10°C increase above 25°C.

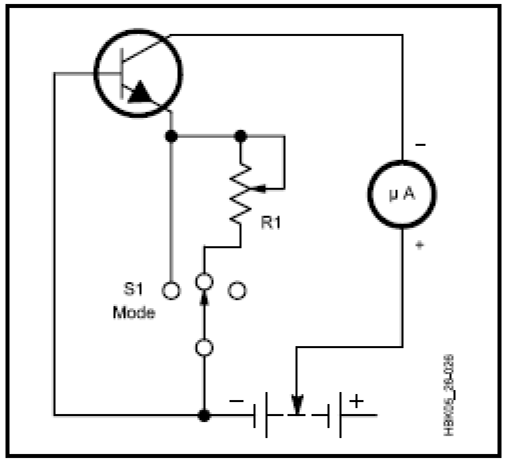


Figure 26.29 — A test circuit for measuring collector-base leakage with the emitter shorted to ground, open or connected to ground through a variable resistance, depending on the setting of S1. See the transistor manufacturer's instructions for test conditions and the setting of R1 (if used). Reverse battery polarity for PNP transistors.

Breakdown-voltage tests actually measure leakage at a specified voltage, rather than true breakdown voltage. Breakdown voltage is known as BV_{cbo}, BV_{ces} or BV_{ceo}. Use the same test fixture shown for leakage tests, adjust the power supply until the specified leakage current flows, and compare the junction voltage against that specified.

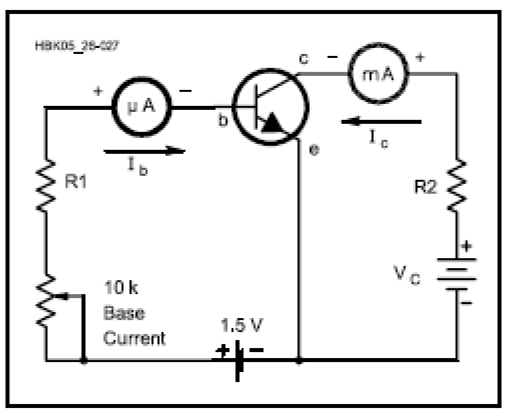


Figure 26.30 — A test circuit for measuring transistor beta. Values for R1 and R2 are dependent on the current range of the transistor tested. Reverse the battery polarity for PNP transistors.

A circuit to measure dc current gain is shown in **Figure 26.30**. Transistor gain can range from 10 to over 1000 because it is not usually well controlled during manufacture. Gain of the active device is not critical in a well-designed transistor circuit.

The test conditions for transistor testing are specified by the manufacturer. When testing, do not exceed the voltage, current (especially in the base circuit) or dissipated-power rating of the transistor. Make sure that the load resistor is capable of dissipating the power generated in the test.

Experiment #35—Power Supply Analysis

The past 34 experiments have tackled individual circuits in splendid isolation. Most electronic equipment consists of several circuits working together. This month, we'll take a common piece of equipment—the linear power supply—and find out why the whole is greater than the sum of the parts.

Introduction

When equipment needs troubleshooting, the schematic diagram for the equipment is opened up and the head scratching begins. While some schematics are a lot easier to read than others, you can tame even the most obtuse by breaking the overall circuit into its various subcircuits, each with a separate job to do.

Before we get started, I'd like to thank the Astron Corporation (**www.astroncorp.com**) for granting permission to reproduce a popular radio supply's schematic diagram, found at **www.repeater-builder.com/astron/astron-rs35m.pdf**. You should also review Experiments #6 (Rectifiers), #8 (Linear Regulator), and #10 (SCRs), all of which are available on the Hands-On Radio Web site, **www.arrl.org/tis/info/HTML/Hands-On-Radio**. A copy of the LM723 voltage regulator's data sheet can be had at **www.national.com/pf/LM/LM723.html#Datasheet**. Ready? Let's go!

Divide and Conquer

The first order of business is to understand the *big picture* by finding out where all of the inputs, outputs, power and controls are located. Most schematics have a flow of signals or power from left to right. A good schematic will also keep components that work together near each other and perhaps even labeled with their function. Before starting to trace a signal or troubleshoot a symptom, take a few minutes to understand how the schematic is organized. Remember the need for clarity the next time you draw a schematic yourself!

Figure 1 shows a schematic of one version of the popular Astron RS-35 power supply capable of supplying 12 V dc at 35 A. (If you have a linear Astron power supply, you might want to open up your unit and "follow along" as we go.) On the left you can see the ac input circuit, and on the right, the dc output terminals. As the power moves from input to output, it goes through a rectifier circuit and then pass transistors that are controlled by a regulator. There is also a mysterious circuit called a *crowbar* that protects equipment against excessive output voltage. I've drawn lines around some of the circuits, while the larger regulator circuit occupies everything in the middle. The numbers in hexagons are connections to the printed-circuit board. The two components labeled RX are only used for power supply testing at Astron.

Input and Rectifier

There's nothing fancy about the input circuit. The hot side of the ac line passes through an 8 A fuse—heavy enough to withstand the current surge at turn-on as the filter capacitors

COURTESY ASTRON

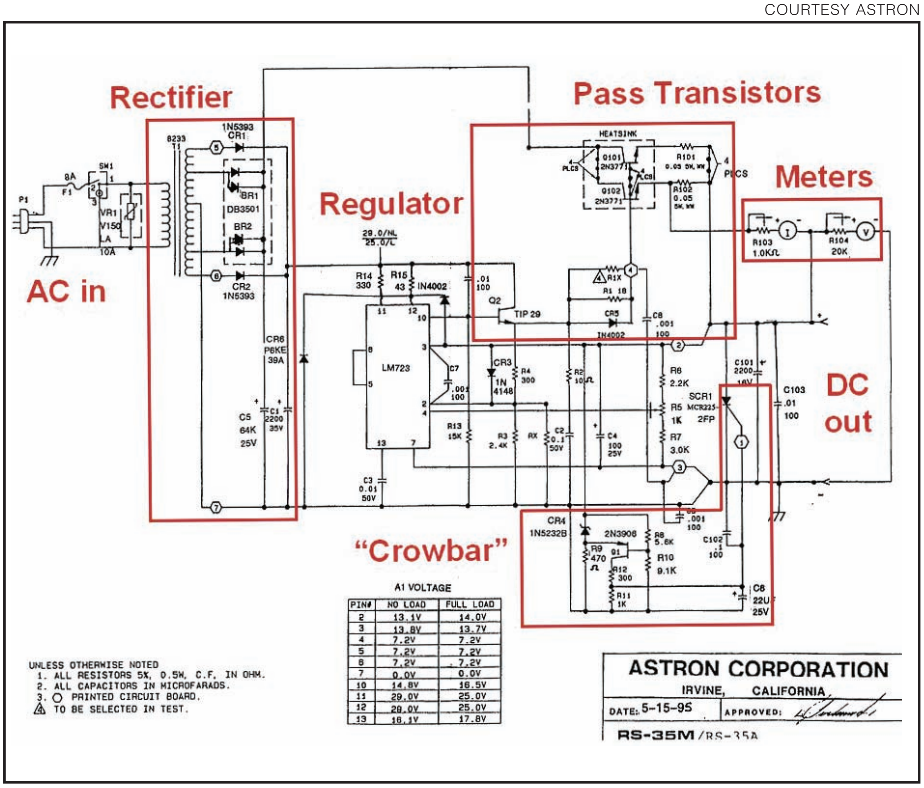


Figure 1—Power supply schematics are best understood with each "subcircuit" analyzed individually. The red lines show the subcircuits. ←

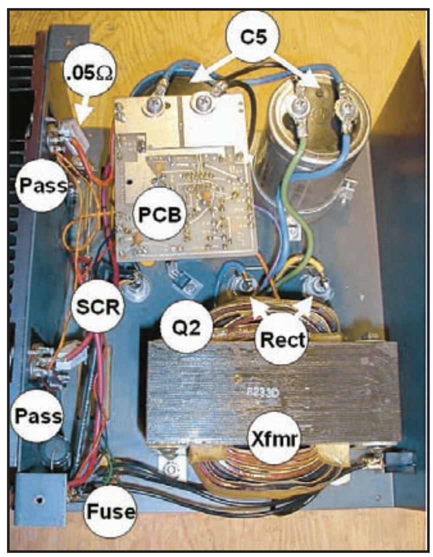


Figure 2—The major components of the power supply. Be careful to avoid contacting the ac line components when measuring voltages!

H. Ward Silver, NØAX ♦ 22916 107th Ave SW, Vashon, WA 98070 ♦ n0ax@arrl.org

charge up. VR1 is a V150LA varistor that conducts at voltages above 150 V, protecting the supply against input voltage surges. (Note—you can usually find detailed information on components by entering their part number and *"data sheet"* with the quotes into an Internet search engine.)

The rectifier circuits look a little strange until you realize that there are two full-wave, center-tapped circuits nested one inside the other. The inner circuit supplies the high current output power. It uses a DB3501 full-wave bridge rectifier (**www.diotec-usa.com/35dbm.pdf**) with the diodes connected in parallel to share the current load. The dashed line around the diodes indicates that they're all in a single package. My model of the power supply in Figure 2 uses two separate diodes. The filter capacitor, C5, is a large 64,000 µF, 25 V electrolytic. My supply has two 32,000 µF caps in parallel. The outer circuit supplies power for the regulator circuitry at higher voltage and much lower current with 1N5393 rectifiers (CR1 and CR2) and C1, a 2200 µF, 35 V electrolytic.

Pass Transistors and Metering

Now follow the output of the high-current rectifier to the pass transistors. Here again, you encounter a dashed line as well as a cryptic notation, 4 PLCS, which means "four places" or "there are four of these." If you look at an actual supply, you'll see four 2N3771 transistor circuits all connected in parallel—that's what the dots mean on the connections between Q101 and Q102.

In order for the transistors to share current equally, 0.05 Ω, 5 W, wire-wound (WW) resistors are in series with the emitter of each transistor. If one transistor begins to hog all the current, the voltage across this resistor increases and lowers its base to emitter voltage, reducing drive and also emitter current. One resistor is used as a shunt, providing a voltage proportional to overall current so that a meter can display total current without having to pass all of it through the meter movement. The current meter, labeled I, conducts a few mA at full scale, as calibrated by R103. A voltage meter is connected directly across the output terminals.

Regulator

Look at the LM723 data sheet and find the equivalent circuit on page 2. This shows how the regulator works without including every transistor. Try to correlate the equivalent circuit with the linear regulator circuit of Experiment #8. In the LM723, the Zener diode is buffered by the voltage reference amplifier (output at pin 6) to improve the stability of the regulator's reference voltage. A "Current Limit" transistor (pins 10 and 11) works by diverting some of the output drive if the output current gets too high.

The LM723 uses a 29 V supply at pin 12, protected by a 1N4002 and CR6, a P6KE39A transient absorber. These protect the regulator IC and clamp any voltage spikes at 39 V. R15 acts to limit the current when a spike occurs, but is small enough not to upset regulator function.

The LM723 compares a fraction the output voltage of the supply (obtained through the voltage divider of R5, R6 and R7) at pin 4 to that of the voltage reference, which is connected to pin 5. If the output is too low the regulator supplies more output drive, and vice versa. Even with high-gain pass transistors, the LM723 can't drive them hard enough to get full output, so Q2, an intermediate driver transistor, is needed—a TIP129. The LM723's internal drive transistor with its collector connected to input power at pin 11 through R14, supplies base current to Q2 from pin 10. So, the LM723 drives Q2, which drives the 2N3771. Q2's output current passes through R1 (18 Ω) and CR5 (1N4002) that limit base drive current to the 2N3771's.

The current limiting transistor inside the LM723 (base connected to pin 2 and emitter to pin 3) is off unless the voltage at pin 2 rises to 0.7 V above the output voltage at pin 3, turning on the internal transistor and diverting drive current from Q2. The values of R3 and R4 set V_{PIN2} to $0.9 \times V_{Q2}$.

Working toward the output from Q2, there is a 0.7 V drop across CR5, another 0.7 V drop from the 2N3771's base to emitter, then 1/4 of the output current times 0.05 W. So V_{PIN2} equals $0.9 \times (V_{OUT} + 0.7 + 0.7 + 0.05\ I_{OUT}/4)$. If the supply is set to the usual output voltage of 13.8 V, the current limiting transistor will turn on when the output current reaches about twice the rated steady state output current, or 70 A. (This is probably high because I assumed a low value of 0.7 V across the power transistors.) CR3 protects the current limit transistor from voltage spikes. There are a number of 0.1, 0.01 and 0.001 µF capacitors in the circuit—they filter out any RF that might upset regulator operation. C4 and C101 filter any sags or spikes at the output due to sudden changes in load.

Overvoltage Protection—The *Crowbar*

This leaves the odd circuit at the lower right, combining a Zener diode, a transistor and an SCR directly across the output of the supply. The function of this circuit is to protect external equipment against excessive voltage due to a supply failure. The remedy is a little extreme—the SCR is turned on, shorting out the supply (and hopefully blowing the input fuse)! It's just like dropping a crowbar across the output terminals and hence the name.

Q1 turns on whenever its emitter is 0.7 V above the base voltage, which is equal to $V_{OUT} \times R10 / (R8 + R10) = 0.62\ V_{OUT}$. Since Zener diode CR4 has a 5.6 V drop from V_{OUT}, Q1 will turn on when $V_{OUT} - 5.6$ V equals $0.62\ V_{OUT} + 0.7$ V, or when V_{OUT} equals 16.6 V. When Q1 turns on, C6 charges up through R12 and triggers the SCR, which dumps current to ground until the supply fuse blows or the filter caps are discharged. R9 keeps Q1 off until CR4 conducts and R11 keeps the SCR off until Q1 turns on.

We've covered the job done by every single component in this power supply! This won't make you a power supply designer, but it should make you a much better power supply troubleshooter! Using the table of voltages at the bottom of the schematic, you can rapidly isolate a problem and get the supply back on the job. Use these same techniques of carving the *big problem* into *little problems* and soon schematics will become much clearer.

Suggested Reading

To follow up on and reinforce what we've learned in this experiment, take a look at other power supply circuits in the *ARRL Handbook*,[1] magazine articles or schematics of other commercial equipment. See if you can break the circuit down into sections. For other regulator ICs, use a search engine to download their data sheets and see how they are used in the circuit.

Next Month

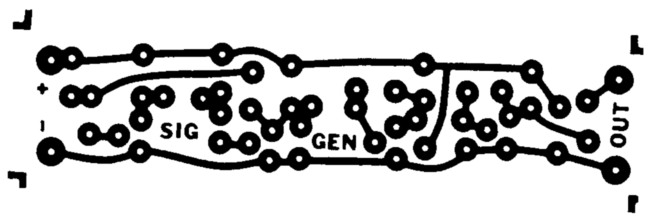
We're going to stick our toes in the deep waters of digital electronics next month by experimenting with an amazingly versatile counter/divider chip that can just about do it all. If you're not familiar with digital electronics, I suggest that you bone up on bit basics by reading the appropriate sections of the *ARRL Handbook*.[2]

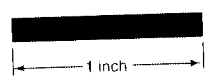
[1,2]Available from your local ARRL dealer, or from the ARRL Bookstore, ARRL order number 9845. Telephone 860-594-0355 or, toll-free in the US 888-277-5289, fax 860-594-0303; **www.arrl.org/shop/**; **pubsales@arrl.org**.

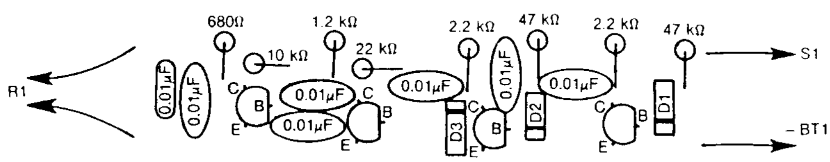
ARRL Handbook CD
Template File

Title: AF/RF Signal Injector
Chapter: 26
Topic: Signal Injector

Template contains: PC board etching pattern and parts placement diagram.







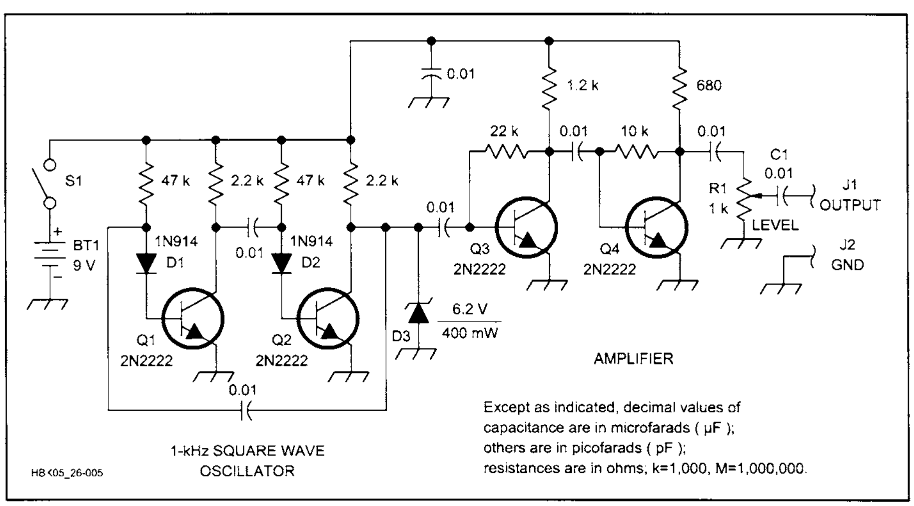


Fig 26.5—Schematic of the AF/RF signal injector. All resistors are 1/4-W, 5% carbon units, and all capacitors are disc ceramic.

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.

Troubleshooting Radios

Before you pack it up and ship it off, check it out yourself.

Mal Eiselman, NC4L

I have been repairing the Yaesu FT-102 HF transceiver for the past 19 years and have spent more than 10,000 hours in this endeavor on this one radio model alone. In all, I have worked through problems in several hundred of these radios over the period. As you may be aware the most significant problem with this radio (as well as many others) is intermittent signal path losses. I am trained as a cardiologist and never had any formal training in troubleshooting RF circuitry, except in my pursuit of perfection for the ’102. During this time I have accumulated a wealth of knowledge in how to track down these problems in the ’102, as well as in most other radios and I would like to share these principles with you.

It’s like the old proverb that if you give a man a fish you feed him for a day but if you teach him how to fish you will feed him for the rest of his life. The principles that I am going to share with you are easy to understand and perform by almost any ham. Finding an intermittent and then sledgehammering it into the ground (I am not speaking literally, of course) so that it never, never occurs again is a true joy and an enormous source of satisfaction. Although my examples are for the ’102 they can be applied to other ham radio equipment.

Let’s Get Started — Here’s What You Need

There are three instruments that you must have. The first is the digital multimeter that most hams already possess. The second is an oscilloscope — nothing fancy is required, since it will be mostly used at audio frequencies. It must, however, be an analog type. Digital ’scopes will not always give you the instantaneous information you need because they are not real time instruments. Good ’scopes can be obtained at hamfests or on the internet for $50 to $100. They are all-powerful when used for troubleshooting (see Figure 1). The third instrument is your own intuitive brain. It is the most important of all the troubleshooting instruments. One other possibility is a low tech signal generator (nothing fancy is needed) and this is required only if your radio does not have a marker or calibrator function. Here is how I troubleshoot a ’102.

The First Step — Get a Signal to Work With

Turn on the transceiver and set the frequency to 14,274.0 kHz, the mode to USB and the RF amplifier to ON. If you can disable the transmitter, do so or be careful not to switch to TRANSMIT during this test. Leave the antenna unconnected. Keep the SHIFT and WIDTH controls centered, straight up on the ’102. Turn on the 25 kHz marker signal (at the back chassis on the ’102) or set your signal generator to 14,275.0 kHz.

If your calibration is close, you should receive a tone of about 1 kHz (14,275.0 – 14,274.0 kHz). Peak the preselector for maximum signal on the S-meter. These maneuvers will provide you with a strong IF signal and 1 kHz audio tone from your speaker because of the USB offset.

Adjust the VOLUME control for minimal audible signal as the sound is not important in this part of the test. If the relays and the rest of the receiver are working properly at that moment you should read a signal of +10 to +15 dB over S-9 on a ’102 and something similar on other transceivers. If you do not have a calibrator in your radio, then an inexpensive signal generator should be used to inject enough power to obtain an S-9 + 10 dB signal. Remember your radio must be on USB with the generator’s frequency 1 kHz above the radio’s frequency to receive the audio tone. The actual audio frequency is not important long as you get a good identifiable tone.

Look at Your Output

Hook up a shielded lead from the AUDIO OUT jack of the radio to one VERTICAL INPUT connector of the scope. On the ’102, I use the AUDIO OUT jack of the six socket RCA connector board on the back of the set. In any other radio, just connect a wire to any audio source including the speaker leads and hook that up to the INPUT connector of your ’scope. Adjust the scope VERTICAL GAIN control or the radio’s AF GAIN control until the signal fills six large vertical divisions centered in the cathode ray tube (CRT) display. Adjust the TIME BASE control for 5 ms/division.

Next, turn the automatic gain control (AGC) circuit to OFF. This switch is on the front panel of the ’102 but other radios may vary. Be careful, as the audio may become very loud and distorted and the signal will be off the scope. Adjust the RF gain control so that the signal level on the CRT screen is at the same level as before pushing the AGC to the OFF position. This will decrease the audio output and its distortion to the previous normal level. Follow the same procedure with any other radio.

At this point any signal path loss — no matter how slight — will be reflected by a change in the signal’s amplitude on the CRT. You will be able to see a 0.1 dB change in level. This is because the AGC is defeated and you are not in saturation of the resulting IF or audio signals. A 6 dB power loss anywhere from the antenna input to the final audio amplifier, will halve the voltage amplitude of the CRT trace. This will be reflected by

Figure 1 — An oscilloscope that is typical of those that can be purchased from eBay or at hamfests for $50 to $100. It is a dual channel ’scope with 35 MHz bandwidth — more than is usually needed.

your audio signal's vertical amplitude dropping from six divisions of the scope (total excursion) to three divisions.

What's it all Mean?

This degree of RF or IF signal loss would not be heard with usual on-the-air circumstances with the AGC engaged. That is because the AGC's function is to compensate so that the audio voltage and volume stay the same even though the input varies. You would not notice a 6 dB difference on an on-air signal with fading (QSB) and static. It is too small a change unless the signal is very near the noise level. Remember, however, that in reality a 6 dB loss represents losing 75% of the power of your received signal. On the other hand when people lose their S meter deflection or their receiver drops out they are having a 60 to 100 dB loss of signal. That magnitude is equivalent to a million to a billion fold loss of signal.

While troubleshooting with a scope you have the ability to see minuscule changes accurately. The sensitivity of this setup permits you to judge accurately when you are losing even small amounts of signal with certainty and thereby detect, locate and repair the defect.

Figure 2 — Only hit the chassis hard enough to get the bounce effect (see text) on the scope pattern. In all testing use good common sense.

Give it a Tap

Okay; now you have the radio in the test mode with everything set up to see even the smallest of losses, if any. But you have to stimulate things. I use the plastic handle of my trusty ratcheted screwdriver and I tap the metal chassis fairly hard (it is best to have the upper and lower cases off) and at the same time I look at the sweep of the CRT for changes as shown in Figure 2.

Even if a radio has no intermittents at all, you will notice that at some point of force with your banging you will encounter relay bounce. This will be a very short loss of the signal on the CRT for perhaps 10 or 20 ms, 2 to 4 horizontal divisions at 5 ms per division. This is normal and represents the fact that the contacts are separating because of the vibrations set up by the percussive force of the screwdriver. This then is the amount of force that you should use to check out the rest of the radio. As I mentioned, the 10 or 20 ms disturbance in the CRT display is normal but if it persists any longer, there are intermittent problems.

If you notice that the level changes to a flat line at the middle of the CRT, there is trouble. Remember, I am a cardiologist and flat lines are very bad! This happens in the most severe cases but most of the time the loss is intermediate and you may only lose 5% of the vertical height. If you hit it again, the pattern may settle on a different level or even return to the prior level. No matter how small the level of change *it is not normal* if it persists. After the 20 ms time interval the level should be exactly back to where it started since the relay bounce phenomena is completed by that time and the contacts should have reseated without any added resistance in the circuit.

Figure 3 — Response to a brisk tap. Note that the sweep is at 5 ms per division. The disturbance persists 4 divisions and then resettles to the same level it was before the strike(s).

Poke to Find the Sensitive Spots

The next thing that you should do is to take a nonconductive plastic pen or plastic tuning wand and tap on the top of each relay in the radio while watching the CRT. Don't use the screwdriver inside the radio. This should be done relatively softly as when the relay is bad it will be quite sensitive. I suggest that you tap each relay several times to make sure, using a repetitive motion. (See Figure 4.)

Next, try tapping and flexing the boards as well as moving the wire harnesses and plugs with the tuning wand. There should be no collapsing of the CRT signal. That will occur with poorly crimped interconnect plugs or fracture traces on the boards, as well as bad relays or components.

The Second Step

This is a similar type of test and complements the above procedure, but it uses sound from the speaker as the watch point.

Change the FREQUENCY control of the radio to read 14,275.00 kHz, right on one of your calibrator harmonics, or the signal generator's actual frequency. Tune until you get a zero beat or just have no tone coming through the audio system. This occurs when the carrier signal and receiver signal are exactly the same. Keep your AGC in the OFF position. Next, turn AF GAIN up as far as it will go with the RF GAIN in the minimal or reduced position. Then advance the RF GAIN control until you just start to get self oscillation or feedback and not a received tone. You should still be receiving the zero frequency — if not, readjust your receiver's tuning to zero it. At that point turn the RF GAIN or AF GAIN control down a notch. In this step you have to be very careful to keep the frequency of the radio and generator the same. If the frequency of either were to shift, it would cause a loud commotion.

Watch Your Ears and Full Speed Ahead

At this point the amplification of everything in the receive path to the speaker is near maximum. Tapping on the boards with the plastic wand will cause an echo-like effect known as a *microphonic*. You will clearly recognize this in the speaker and it is a normal effect of vibrating the boards by tapping them. With an intermittent, however, the sound from your speaker will sound like three ball bearings rolling around in a tin can. You should not hear a crackly or clunky distorted sound anywhere in the radio with one exception.

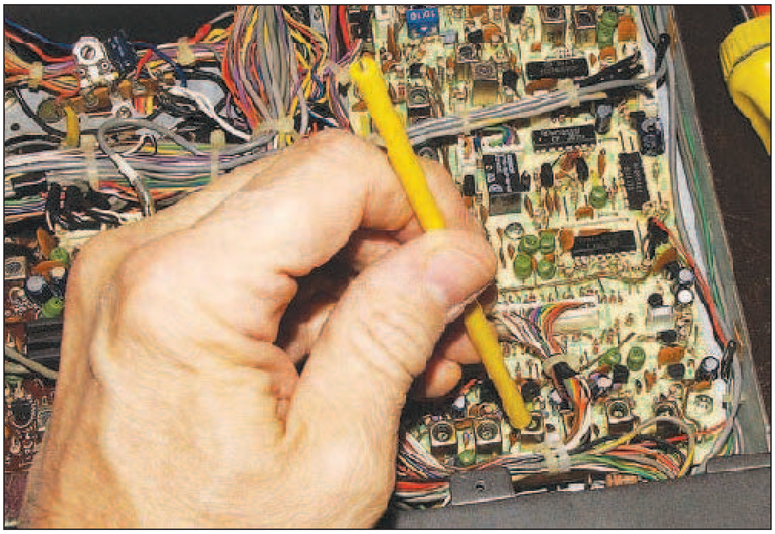


Figure 4 — Flex the boards and tap the components. Be careful if there is high voltage present as fingers sometimes slip.

The clunky or crackly sound is okay if you hit a can or adjustment coil that is part of the frequency control circuitry for the voltage controlled oscillator. In the ’102 these circuits are in six cans on the front of the local oscillator board. In Figure 4 the tuning wand is touching one. As you get farther and farther away from those sensitive points, the clunky and crackling sounds should decrease and then disappear. It is normal for the microphonic effect to persist. With a little practice and attention you will quickly know what is normal and what is not.

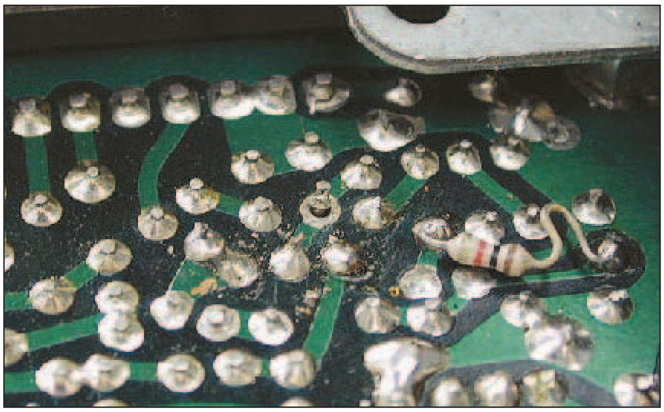


Figure 5 — Note the witch’s hat fracture in the center of the photo. The lead coming from the component side of the board has a circumferential fracture and separation of the solder filet. I have seen these many times. They are usually not as obvious. There are three others in this photo. *Hint — look up*.

Tap and flex all the relays, boards and wires in the radio as you did before with the plastic wand. Tap the bandswitch shaft and anything else you come across with the plastic wand to see if there are signs of a signal intermittent or loud crackly noises. Be careful not to get shocked. You may not know the danger points and places where high voltage resides so be very careful with tube radios. There should be no danger of shock in 12 V radios, but beware of high current shorts that can cause damage.

Any bad component, dirty bandswitch wafer, poor crimp connection, witch’s hat fractures (see Figure 5) or bad relays will, for the most part, be most sensitive at its precise location. If you find a bad spot use lesser and lesser tapping force to narrow the precise area (sort of like playing hot and cold when you were a kid). When you get things localized, check the components and also visually check the trace side of the board after removing it from the radio.

Step Three

Using a signal generator or calibrator, the procedures so far will check all but one signal path in the receiver section of an FT-102. What remains is comprised of the antenna switching relay and the antenna input circuitry. If you are using an external generator you will not need to do this step as that signal runs through those components. But an internal marker signal is inserted following those elements in many radios, including the ’102. The following procedure checks the remaining receive path in the ’102.

With the radio off, connect a digital ohmmeter across the SO-239 antenna jack. I use an alligator clip on the ground post for one lead. You need to make good contact or this test will be invalid. I press the other lead of the ohmmeter into the SO-239 central hole and hold it there with solid pressure.

The ohmmeter should read between 8.5 and 9.5 Ω. That represents the impedance of the fuse bulb in the Yaesu FT-102 — your radio may read differently. Then while watching the ohmmeter, use the back of the screwdriver and bang it against the upper back chassis above the transmit cage until you see the loss of conductivity representing relay bounce. In order to pass this test the digital ohmmeter reading should be back to within 0.1 Ω of where it started within two update periods of the digital display. Remember here that a persisting 0.5 Ω difference after hitting the chassis means there is a resistance blockage on the contacts of the relay or on the relay board or its interconnects. With time and changing temperatures this may blossom to an intermittent and perhaps eventually an open circuit. That can easily happen the next time you use the radio.

The Final Part — The Transmitter Section

We now need to do the same kind of process for the transmit signal path since losses can occur there as well. For this test use a dummy load and apply 20 W of continuous power (key down CW) so that you don’t cook anything including the tubes in the ’102. Use the same power output for other radios as well as full output here will not give an accurate account of things. If you are technically inclined and can connect the scope to the power output, that is the best way to see output changes. If you are not experienced enough to do, then use a power output meter.

Watch the output of the radio by connecting it to the ’scope or meter. Use 5 ms/division as before for the scope trace and make the vertical pattern about 75% of the full CRT screen. A power output meter will be helpful but it will not be quite as sensitive or immediate as an analog ’scope monitoring the events.

Then get your trusty screwdriver and plastic pen/plastic tuning wand and test the transmitter in the same way as you did the receiver. In this step, as you percuss the test radio, listen to its signal on the second receiver as you watch the ’scope. Remember, watch out for high voltage in unfamiliar surroundings and always use an insulated instrument to apply force.

After the visual testing listen to the transmitted CW signal in a second receiver.

Listen on the zero beat frequency with the receiver set to USB or LSB. Turn the volume of the second radio way up and listen for the microphonics and clunking resulting from stressing the boards and wires with the percussive devices in the transmitting radio. This then completes the whole procedure.

And Then What?

If you detect a fault, zero in on it until you locate it or isolate it to two or three components. Then examine those and repair or replace them. In addition, check the solder side of the board for irregularities. Use a good magnifier and light as witch hat fractures can be hard to see.

Finally, I call this quadruple stress testing of the transceiver. Please forgive my use of terms but it does convey the message and ideas properly although it is a difference kind of stress.

I believe I have told you more than you wanted to know. But that is how to troubleshoot the ’102 or any other ham radio for intermittents, whether from relays (not always the cause) or anything else. If you are careful and meticulous with this method you will eventually track down every cause of signal loss. One last point before we end and you pull your old radios out for testing: In all my years of doing this I have never found an intermittent in a radio using heat or cold where percussion didn’t work.

Becoming conversant with these procedures will help make you a competent technician and enable you to repair and rescue radios that other hams would relegate to the scrap yard. It will also give you a feel for radio design and radio principles. I know it did that for me. Good luck and keep the ionosphere warm.

ARRL member Mal Eiselman, NC4L, has been licensed since 1961 and has been a member of the ARRL for the past 30 years. He currently holds an Amateur Extra class license. He is a trained cardiologist who practiced in Hollywood, Florida for 30 years before retiring in 2003. His love of electronics and ham radio led him to repairing and modifying his Yaesu FT-102 HF transceiver. It is the only radio that he repairs and he has done this for the past 19 years. His Amateur Radio interests include keeping in contact with old friends as well as making new friends on the air on a daily basis. His second interest is making electronic things work better. You can reach the author at 3650 N 55th Ave, Hollywood, FL 33021 or at **NC4LMal@aol.com**. *Visit his Web site at* **www.w8kvk.com/nc4l**.

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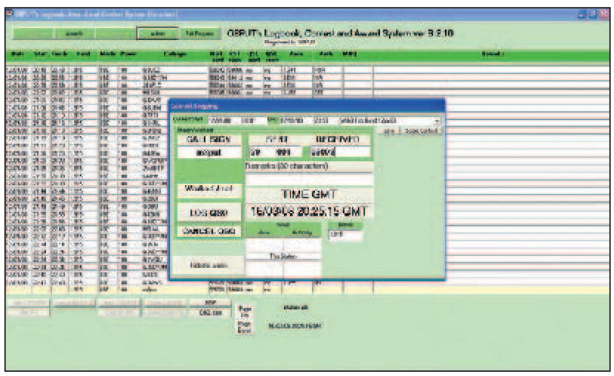

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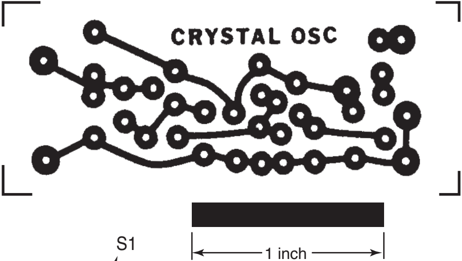

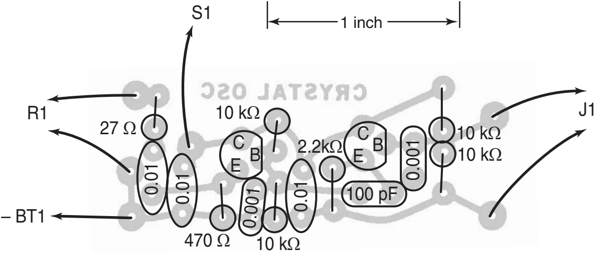

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