Building a Modern Signal Tracer

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

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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.

[1]Notes appear on page 44.

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.

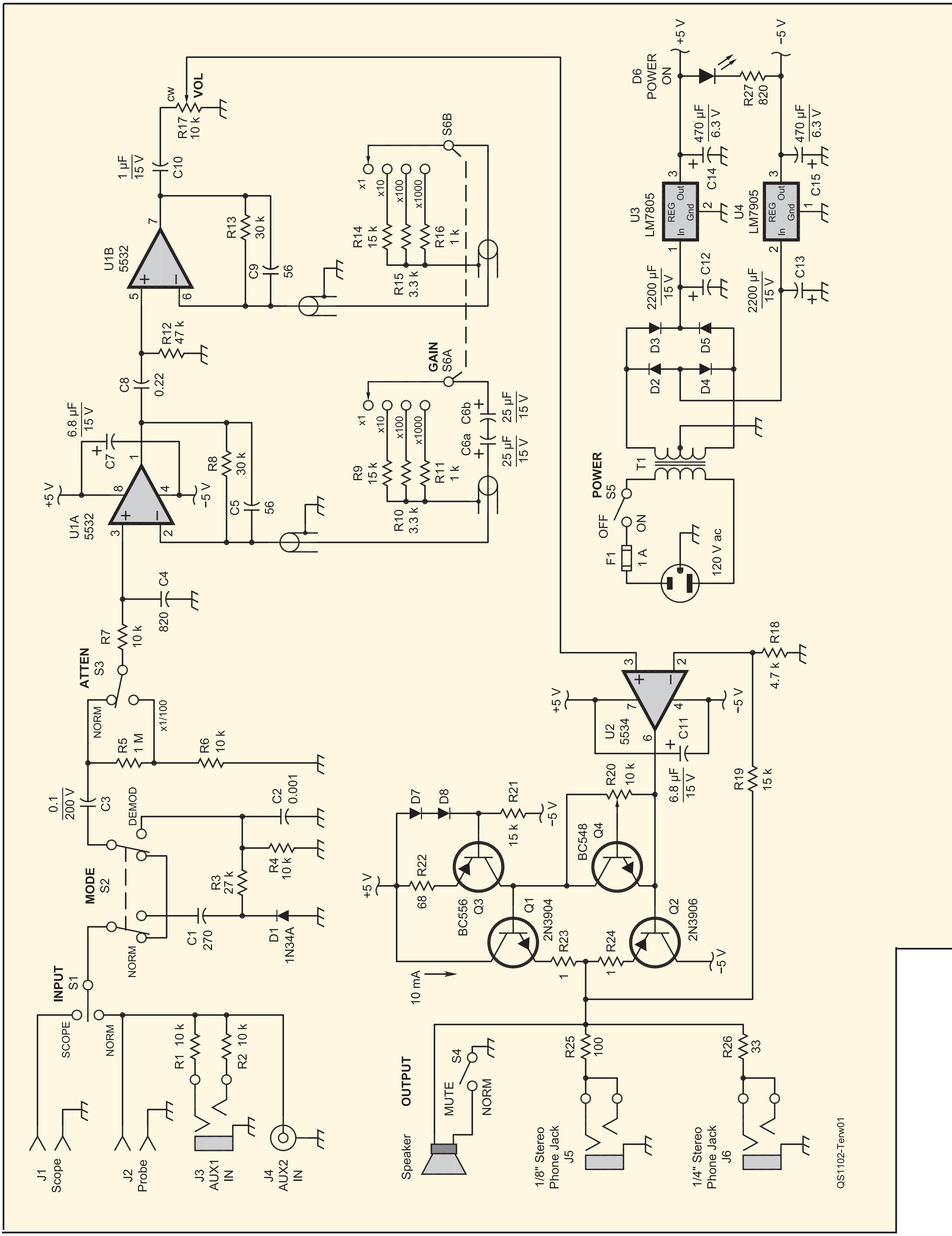
J1
Scope
J2
Probe
J3
AUX1
IN
J4
AUX2
IN
INPUT
S1
SCOPE
NORM
R1 10 k
R2 10 k
MODE
S2
DEMOD
C1
270
D1
1N34A
R3
27 k
R4
10 k
C2
0.001
C3
0.1
200 V
ATTEN
S3
x1/100
R5
1 M
R6
10 k
R7
10 k
C4
820
U1A
5532
C7
6.8 µF
15 V
+5 V
–5 V
R8
30 k
C5
56
C8
0.22
R12
47 k
U1B
5532
R13
30 k
C9
56
C10
1 µF
15 V
R17
10 k
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
U3
LM7805
U4
LM7905
REG
In
Out
Gnd
C12
C13
C14
C15
2200 µF
15 V
470 µF
6.3 V
D2
D3
D4
D5
T1
POWER
S5
OFF
ON
F1
1 A
120 V ac
U2
5534
C11
R18
4.7 k
R19
15 k
R20
10 k
R21
15 k
R22
68
R23
1
R24
1
D7
D8
Q1
2N3904
Q2
2N3906
Q3
BC556
Q4
BC548
10 mA
OUTPUT
S4
MUTE
NORM
Speaker
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).

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]

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*.

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}

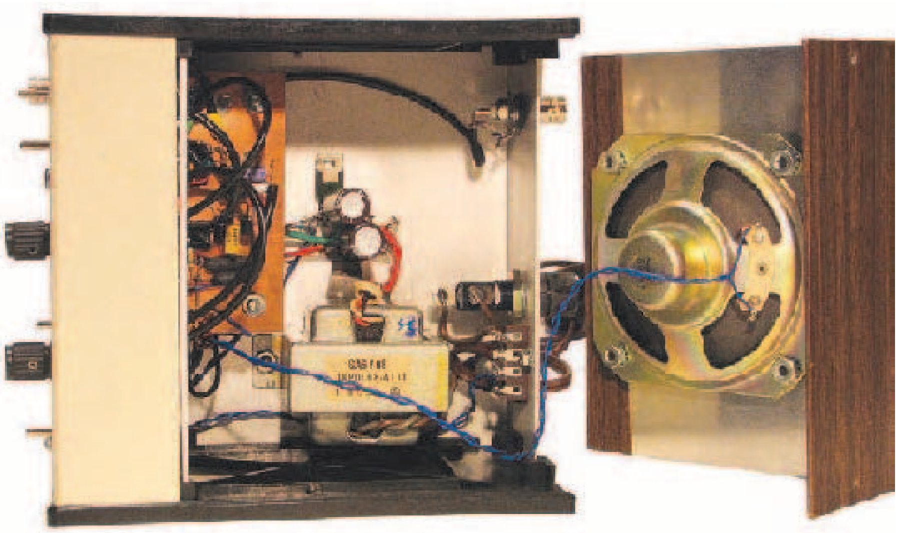

Figure 4 — View of the circuit using dead bug style of construction on a piece of copper clad board. The wiring method is not critical — just avoid ground loops.

(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**.