Exploring RF

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Modeling a Direct-Conversion Receiver's Audio Response and Gain with *ARRL Radio Designer*

You can just about go bonkers in getting started with a powerful tool like *ARRL Radio Designer*[1] if doing so means doing too many all-new things at once. That's one of the reasons why *ARD* ships with seven example circuits:[2]

- a double-tuned-circuit filter for 13.975 to 14.475 MHz
- a gang-tuned double-tuned-circuit filter for 80 meters
- a simple JFET MF/HF preamp
- a BJT post-mixer amplifier with feedback
- an op-amp audio filter
- a six-crystal ladder filter for 3.579545 MHz
- a 9-MHz diplexer

The examples are there to help you learn the *ARRL Radio Designer* way of doing things, of course, but they are also intended to demonstrate that *ARD* can do a good job of telling you things you already know. (Maybe *you* don't check each year's new *White Pages* to see if your phone number is correct, but I use that simple test to determine whether or not there's hope for the rest of the book!) Once you're satisfied that a new tool can do the old jobs you know, you're more likely to trust it to do new jobs your old tools can't do.

This month's modeling example—simulating the audio channel of a heterodyne direct-conversion receiver[3]—is another potential *ARD* trust-builder. Many of us have built heterodyne direct-conversion receivers, so we know what they do: They heterodyne RF signals to AF, amplify the resulting audio, and shove it at us through electroacoustic transducers (headphones or speakers). (Actually, this is also all a superheterodyne receiver ultimately does. The difference is that a superhet also does one or more RF-to-RF conversions before completing that final RF-to-AF conversion.)

Although *ARRL Radio Designer* can't model frequency conversion or transducer action, it can make itself pretty useful in helping us understand, design, and modify the linear subsystems in a direct-conversion radio. Roger Hayward's "Ugly Weekender" receiver (June 1992 *QST*[4])—a sound, friendly direct-conversion design for 7 MHz—is a good example for study because most of its active devices are easily modelable discrete transistors. (I personally like the Ugly Weekender because it's easy to build, uses no hard-to-get parts, and sounds like a real radio. Connect it and its companion 1.5-W transmitter to a low half-wave dipole just after lunch some Saturday or Sunday, and you'll have to work hard *not* to contact someone on QRP CW.)

The entire Ugly Weekender Receiver (UWR) schematic covered a full *QST* page. Our *ARD*ized UWR schematic (Figure 1) takes less space because we need to model only four of the original's 11 transistors—just those that amplify and band-limit the UWR's audio. Table 1 shows Figure 1 in *ARRL Radio Designer* netlist form.

Netlist Highlights

Structure

How we structure an *ARRL Radio Designer* netlist for a particular circuit depends somewhat on what we want to know about the circuit we're modeling. We know, for instance, that a direct-conversion receiver containing little or no RF amplification—the UWR uses none—must be capable of something like 80 to 100 dB of audio gain. We also know (by carefully reading citation trails through several articles' worth of footnotes) that the UWR's first audio preamp was designed to terminate the receiver's double-balanced diode mixer in something reasonably close to 50 Ω, resistive, at least in the audio range. Since we're out to see whether *ARRL Radio Designer* can correctly tell us things we already know, what we already know is what we want to find out.

The Table 1 netlist represents the Ugly Weekender Receiver in three circuit blocks—`MIXER`, `Q8-9-10` and `Q12`—so we can

[1]Notes appear on page 78.

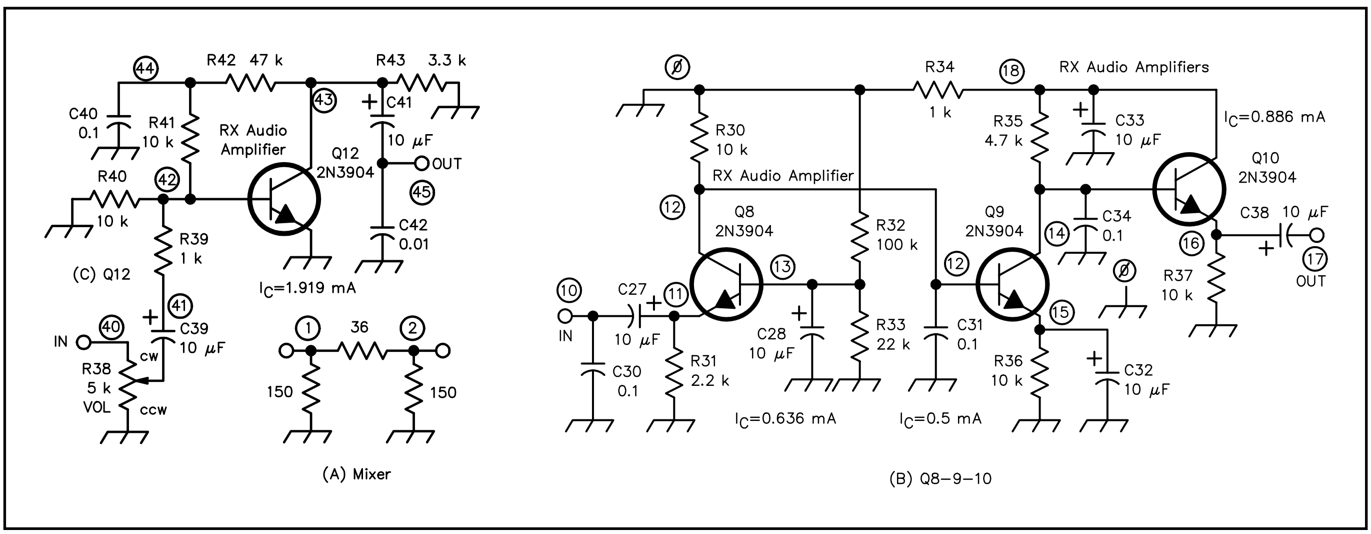

Figure 1—We need concern ourselves with only four of the Ugly Weekender Receiver's 11 transistors in modeling its basic performance with *ARRL Radio Designer*. I added the circled *node numbers* as I coded the circuit into an *ARD* netlist (Table 1).

Table 1
Simulating the Ugly Weekender Receiver's Audio Amplifier with *ARRL Radio Designer*

```
BLK ; this is MIXER (Figure 1A)
 RES 1 0 R=150
 RES 1 2 R=36
 RES 2 0 R=150
MIXER:2POR 1 2
END
BLK ; this is Q8-9-10 (Figure 1B)
 CAP 10 0 C=0.1UF      ; C30
 CAP 10 11 C=10UF      ; C27
 BIP 13 12 11 A=0.99 RE=(26/0.636); Q8
 RES 12 0 R=10KOH      ; R30
 CAP 13 0 C=10UF       ; C28
 RES 13 0 R=22KOH      ; R33
 RES 13 0 R=100KOH     ; R32
 CAP 12 0 C=0.1UF      ; C31
 BIP 12 14 15 A=0.99 RE=(26/0.5); Q9
 RES 15 0 R=10KOH      ; R36
 CAP 15 0 C=10UF       ; C32
 RES 14 18 R=4.7KOH    ; R35
 RES 18 0 R=1KOH       ; R34
 CAP 18 0 C=10UF       ; C33
 CAP 14 0 C=0.1UF      ; C34
 BIP 14 18 16 A=0.99 RE=(26/0.886); Q10
 RES 16 0 R=10KOH      ; R37
 CAP 16 17 C=10UF      ; C38
Q8-9-10:2POR 10 17
END
BLK ; this is Q12 (Figure 1C)
 RES 40 0 R=5KOH       ; R38 (GAIN control at max)
 CAP 40 41 C=10UF      ; C39
 RES 41 42 R=1KOH      ; R39
 RES 42 0 R=10KOH      ; R40
 RES 42 44 R=10KOH     ; R41
 CAP 44 0 C=0.1UF      ; C40
 RES 44 43 R=47KOH     ; R42
 BIP 42 43 0 A=0.99 RE=(26/1.919); Q12
 RES 43 0 R=3.3KOH     ; R43
 CAP 43 45 C=10UF      ; C41
 CAP 45 0 C=0.01UF     ; C42
 Q12:2POR 40 45
END
BLK ; this block chains MIXER, Q8-9-10 and Q12
 MIXER 10 20
 Q8-9-10 20 30
 Q12 30 40
 SYSVGAIN:2POR 10 40
END
FREQ
 ESTP 20HZ 20KHZ 500
END
```

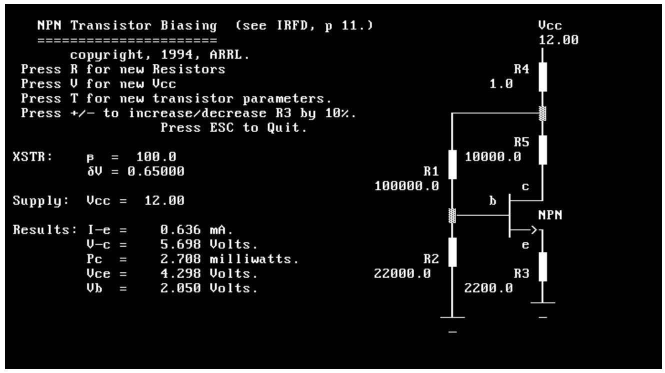

Figure 2—Wes Hayward's *NPNBIAS.EXE*, one of over 20 utilities on the software disk shipped with ARRL's reissue of his *Introduction to Radio Frequency Design* book, provided me with the collector currents coded into the BIP netlist lines in Table 1.

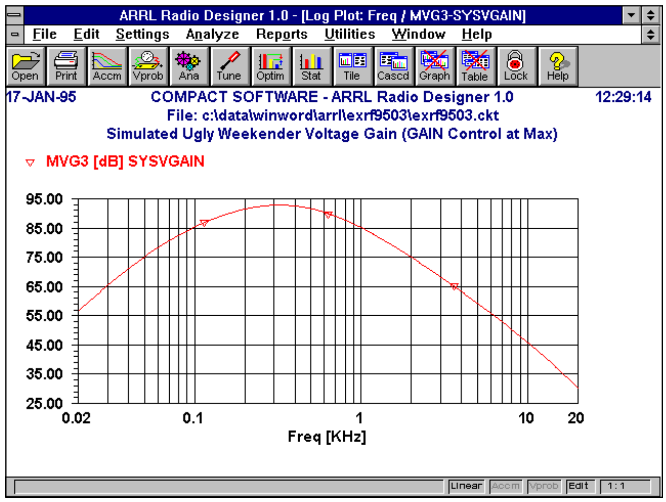

Figure 3—*ARRL Radio Designer* can evaluate voltage gain in several ways. This graph merely expresses in decibels the ratio of the UWR's output voltage (at the output terminals of the `Q12` block, terminated in 2000 + *j*0 Ω, the circuit's anticipated headphone load) to input voltage (at the input terminals of the `MIXER` block, with `MIXER`'s input terminated in 50 + *j*0 Ω)—just the sort of measurement we're implying when we say that a direct conversion receiver must have "80 to 100 dB" of audio gain. Our model predicts that the Ugly Weekender Receiver's maximum audio gain—without its optional LM386 audio power amp IC—is just under 94 dB at its passband peak.

zero in on the radio's subsystems. To model how these blocks work together as one big system, we chain them end to end (using a new set of arbitrary node numbers that happen not to duplicate those of the constituent blocks) in a fourth netlist block:

```
BLK
 MIXER 10 20
 Q8-9-10 20 30
 Q12 30 40
 SYSVGAIN:2POR 10 40
END
```

ARRL Radio Designer will use this block to calculate the Ugly Weekender's overall audio voltage gain, so we'll name it `SYSVGAIN`.

Finally, we tell *ARD* to calculate these four blocks' performance at 500 exponentially stepped frequencies from 20 Hz to 20 kHz:

```
FREQ
 ESTP 20HZ 20KHZ 500
END
```

Transistors

The Table 1 netlist models the Ugly Weekender's four 2N3904 bipolar junction transistors (BJTs) with *ARD*'s BIP element. Because our modeling goals are simple—we're pretty much after just gain and impedance, and at audio frequencies to boot—we can get away without specifying any more than the transistors' alphas and emitter resistances, which happen to be the only two BIP parameters *ARD* absolutely can't live without.

An alpha of 0.99—corresponding to a beta of 100—is a safe assumption for a garden-variety small-signal transistor like the 2N3904. For emitter resistance (RE), we insert a formula (26 [°C, that is—room temperature] ÷ collector current in milliamperes) that comes from the well-established transistor model developed by Ebers and Moll. Yanked out of Table 1 and grouped, the UWR's four 3904s look like this:

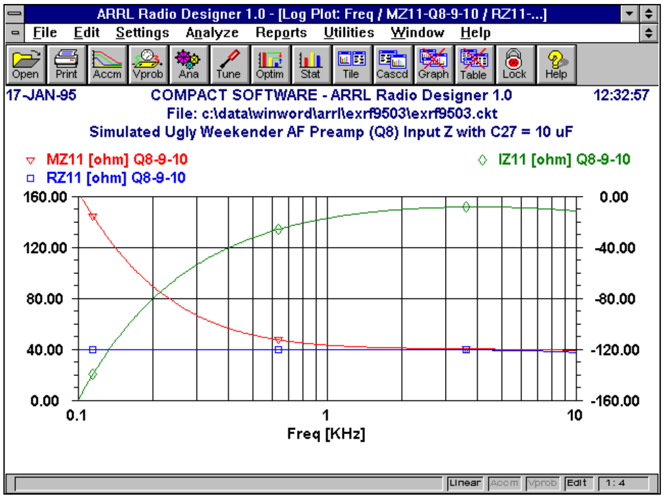

Figure 4—The Ugly Weekender's first audio preamp, Q8, is biased to terminate the radio's mixer with a resistive load reasonably close to 50 Ω across the span of common CW receiving pitches. *ARRL Radio Designer* can report complex impedances in magnitude and R + *j*X (that is, real-imaginary) form, so this graph shows Q8's input impedance in terms of magnitude (MZ_{11}, triangular marker, 0 to 160-Ω scale), resistive component (RZ_{11}, square marker, 0 to 160-Ω scale) and imaginary (reactive) component (IZ_{11}, diamond marker, 0 to –160-Ω scale.

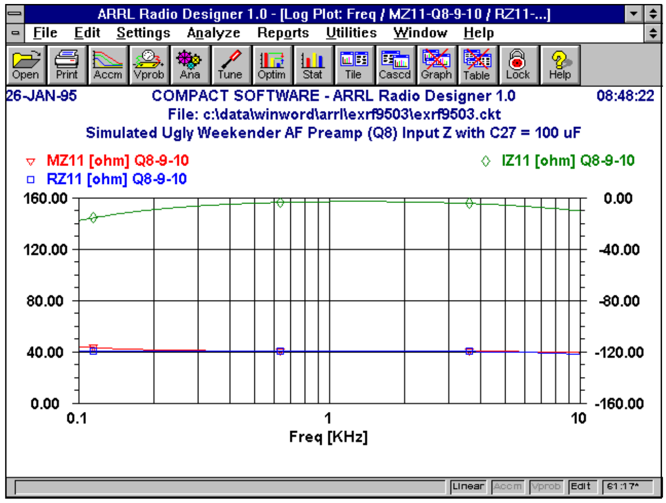

Figure 5—Finally, in five acts, a "what if?" detective vignette from the tattered casebook of Inspector *ARD*: (1) If Q8's input impedance is supposed to be flat and resistive across our audio range of interest, how come its magnitude (Figure 4's MZ_{11} curve) takes off so noticeably below 1 kHz? (2) Hey, the imaginary part of Q8's input impedance—Figure 4's IZ_{11} curve—pretty much tracks the *reciprocal* of that MZ_{11} rise over the same range! (3) Hmm, that IZ_{11} curve shows only negative values. By convention, we ascribe negative numbers to capacitive reactance, so the culprit must be a capacitor between the circuit's input terminal and Q8's emitter. (4) That would probably be C27, shown as 10 µF in Figure 1. Come to think of it, 10 µF does seem a bit small for a part that's supposed to act as a low-Z series element down to a few hundred hertz. So what would happen if we made C27 100-µF instead? (5) Answer: a Q8 input impedance that's almost purely resistive from 100 Hz to 10 kHz. Case closed!

```
BIP 13 12 11 A=0.99 RE=(26/0.636); Q8
BIP 12 14 15 A=0.99 RE=(26/0.5); Q9
BIP 14 18 16 A=0.99 RE=(26/0.886); Q10
BIP 42 43 0 A=0.99 RE=(26/1.919); Q12
```

We could hand-calculate the transistors' collector currents, of course—a drag—or snip our own Ugly Weekenders' 2N3904 collector leads and measure the currents (highly recommendable to keep your modeling on the rails, if you can take the time). Short on time, I instead used *NPNBIAS.EXE* (Figure 2), one of the 20+ utility programs included on the software disk shipped with ARRL's hot-off-the-press reissue of Wes Hayward's *Introduction to Radio Frequency Design* book, to give me ballpark collector-current numbers.

Modeling Results

Figures 3, 4, and 5 tell the rest of the story. Our Ugly Weekender Receiver model predicts realistic audio gain—just below 94 dB, max—and a useful degree of AF bandwidth limiting. And Q8, the UWR's post-mixer preamp, does indeed exhibit a reasonably resistive input impedance that's reasonably close to 50 Ω across the audio range of interest.

Now you'll have to excuse me—this modeling has got me so revved up about the Ugly Weekender that I think I'll go contact somebody with the real thing!

Free Electronic Goodies

You can get expanded versions of the Table 1 netlist in the file EXRF9503.TXT, available from the ARRL HQ BBS (203-666-0578) and Internet info server (*info@arrl.org*). As always, the latest *ARRL Radio Designer* news is also available from those sources in the file ARD.TXT.

Notes

[1]David Newkirk, WJ1Z, "Introducing ARRL Radio Designer: New Software for RF Circuit Simulation and Analysis," *QST*, Oct 1994, pp 21-26.

[2]Seven *circuits*, but eight *examples*. *ARRL Radio Designer*'s Example 2 is just Example 1—the 20-meter filter—with at least one error intentionally added to each of its netlist lines to give you experience in debugging a buggy *ARD* circuit file.

[3]I used the adjective *heterodyne* here to give us an imperfect start in differentiating among the various types of direct-conversion receivers, which have actually always included "crystal radios" and regenerative receivers (oscillating or not). *Any* receiver that converts RF directly to audio is a direct-conversion receiver, our tradition of using the term more narrowly notwithstanding.

[4]Roger Hayward, KA7EXM, "The 'Ugly Weekender' II: Adding a Junk-Box Receiver," *QST*, Jun 1992, pp 27-30.

New Products

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◊ *PC PakRatt for Windows 2.0* from Advanced Electronic Applications is a full-featured *Windows*-based control program that's aimed at power users of AEA's entire line of multimode data controllers (PK-900, DSP-1232, DSP-2232, PK-88 and the PK-232MBX). Version 2 also supports the PK-96 1200/9600-bit/s packet controller and the PK-12 1200-bit/s packet controller.

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Other features: simplified mail-drops; file transfers; split-screen operation; macros; built-in QSO logging; compatibility with AEA's *Log Windows 2.0* software; and more. Requirements: At least one of the above-mentioned AEA multimode data controllers and an IBM-compatible computer running Microsoft *Windows*.

Price: $129; available from AEA or your local Amateur Radio dealer. Upgrades for users of version 1.0 are available from AEA. Contact Advanced Electronic Applications at PO Box C2160, Lynnwood, WA 98036; tel 206-774-5554, fax 206-775-2340.