Edited by **David Newkirk, WJ1Z** • Electronic Publications Editor

ARRL Radio Designer versus Oscillators, Part 1

ARRL Handbook Author David Stockton, GM4ZNX, isn't kidding when he writes, in the 1996 *Handbook*'s "AC/RF Sources" chapter, of "the well-known propensity of all prototype amplifiers to oscillate!" Sooner or later, just about everyone who builds circuitry capable of amplifying audio or radio signals forcefully experiences this truth. All sustained oscillation requires is sufficient gain, positive feedback (signal fed from an amplifier's output back to its input in phase with the input signal), and filtering (in effect, a means of determining the frequency of oscillation) in the feedback path. With those requirements met and power applied, random noise in the amplifying device(s) is often enough to get the system started, and *presto*: You've built an oscillator!

The presence of oscillation is always important, even when you don't want it. "All intentionally transmitted signals trace back to some sort of signal generator," writes Stockton, and so it follows that communication by radio depends on our ability to make circuits oscillate when we want them to. But it also follows that *un*intentional signal generation can cause *un*intentionally transmitted signals. As if that isn't problematic enough from a transmitting standpoint, unwanted—we sometimes say *parasitic*—oscillations can seriously degrade audio and receive-only RF circuit operation, too.

Even if it doesn't end up on the air, unwanted oscillation can spoil the operation of circuitry that harbors it because it's a *large-signal* effect—it causes active devices to operate under bias and supply conditions vastly different from those called for by linear design. Parasitic oscillations can cause distortion of, and intermodulation with, desired signals—if desired signals get through the oscillating circuitry at all. If it's strong enough, an unwanted oscillation can even cause component damage—quite possibly the result of, say, a strong post-mixer amplifier "taking off" and blasting the crystal filter following it with QRP-transmitter-level RF.

If you're new to computerized RF-circuit simulation, you may be surprised to learn that *ARRL Radio Designer* 1.5 (*ARD*)[1] can't directly simulate something so apparently simple, and so fundamental to radio communication, as oscillation. But oscillation is *not* simple. Small-signal, ac circuit simulator that it is, *ARRL Radio Designer* isn't capable of doing the complex dc, nonlinear-ac and time-domain analyses necessary to realistically simulate oscillation (and mixing and rectification). For example, *ARD* simulations assume that signals applied to a circuit are small enough not to shift the operating points of active devices—but self-induced operating-point shift is one way oscillators routinely achieve amplitude stabilization. Programs capable of doing accurate large-signal simulation of such effects are available, of course—*Microwave Harmonica*, one of *ARD*'s bigger Compact Software siblings, comes to mind, as do various high-end *SPICE*-based simulators, among others—but the truly RF-suitable programs among them are expensive from the hobbyist's point of view and require considerable user smarts to produce true-to-life results.

Even though it's "only" a small-signal simulator, *ARRL Radio Designer* 1.5 *can* do something that's quite useful if you want to achieve stability or oscillation by design: It can reliably indicate whether or not oscillation is possible or likely. We'll begin our exploration of two means to this end by looking at a circuit that wasn't supposed to oscillate, but did.

ARD and the Oscillating Preamplifier

Jacob Makhinson, N6NWP, designed and built a low-noise broadband preamp that used two MRF586 transistors in push-pull (Figure 1) as part of a high-dynamic-range receiver front end he presented in *QST*.[2] Based, as it is, on the lossless feedback configuration developed by David Norton,[3,4] the preamp uses two

[1]Notes appear on page 69.

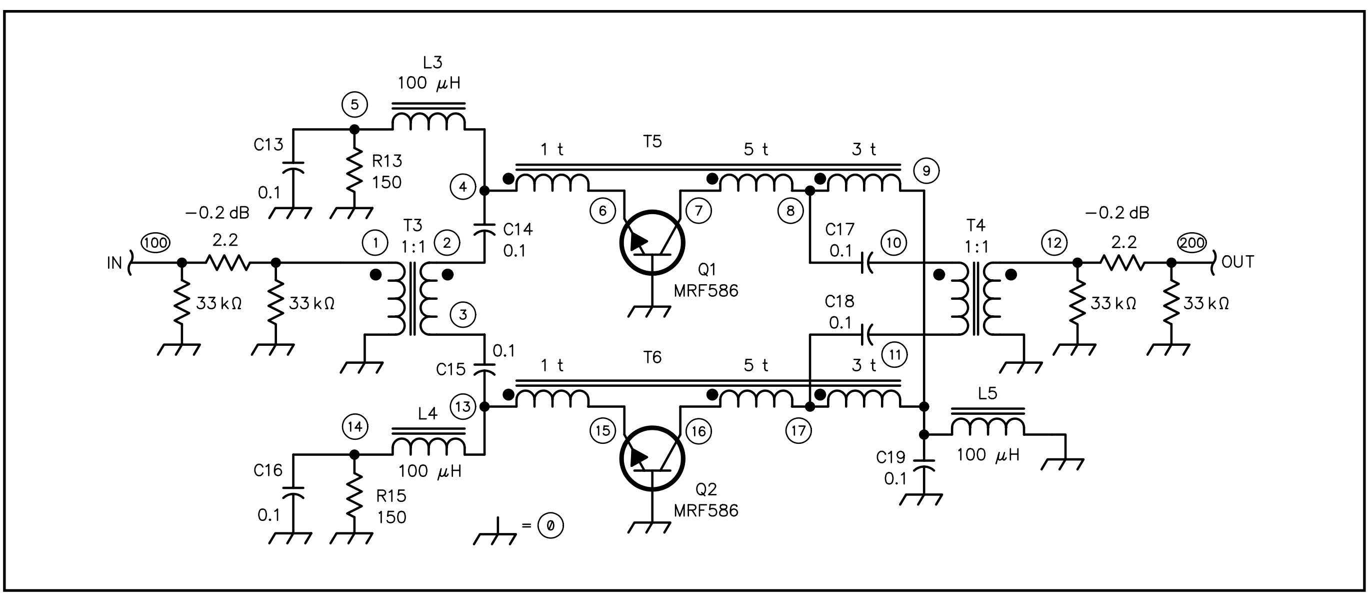

Figure 1—Jacob Makhinson's push-pull MRF586 preamp uses Norton's lossless feedback technique to achieve a low noise figure (less than 3 dB) and low distortion. (The 0.2-dB pads simulate loss in T3 and T4.) Proper construction and connection of T5 and T6 are critical, as the early few who worked to duplicate the circuit learned. See Figures 2 and 3.

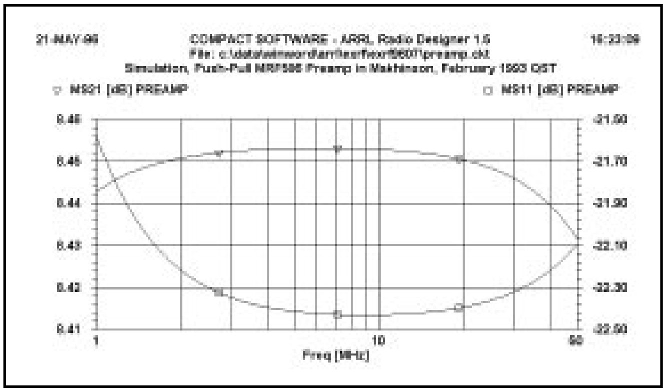

Figure 2—With T5 and T6 built and installed properly, the circuit behaves as its designer intended. Our simulated preamp's gain (MS_{21}) is within 0.5 dB of that measured by Makhinson; its input return loss (MS_{11}) indicates a good match to 50 Ω.

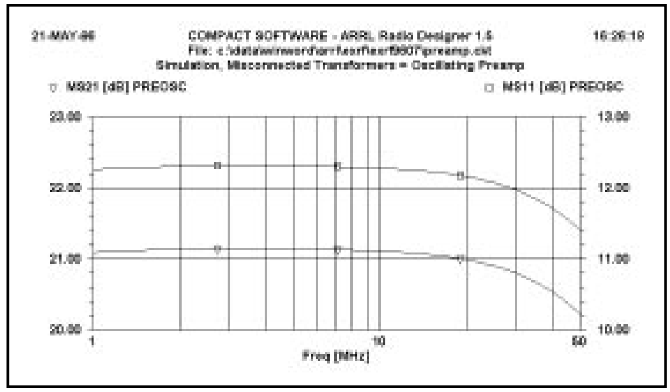

Figure 3—In this simulation, based on the T5 and T6 misconnection presented in the original article's Figure 9, *ARRL Radio Designer* reflects the presence of that in-phase feedback as a *positive* value for MS_{11}. Those who built the circuit before seeing the June 1993 correction had already learned the hard way that positive feedback would result in a fine push-pull *oscillator!*

three-winding transformers to apply the negative feedback critical to the circuit's simultaneous achievement of low noise, useful gain, high dynamic range, and a good match to 50 Ω.

In our simulation of this preamp, two *ARD* bipolar junction transistor (BIP) elements, configured to act like real MRF586s through S-parameter-based optimization (as described in "Exploring RF" for July and September 1995), serve as the modeled preamp's active devices. Jacob Makhinson biased the preamp's MRF586s to draw 25 mA at 6 V, so I based my BIP optimization on MRF586 S parameters derived at 30 mA and a collector-to-emitter voltage (V_{CE}) of 5 (the closest MRF586 S-parameter data available in the *ARRL Radio Designer* 1.5 databank [Bank01] file motorola.flp). I optimized the BIP to an error function of 0.0756172 at 100 MHz.

Figure 2 shows the circuit's simulated gain (MS_{21}) and input return loss (MS_{11}). Our simulation achieves gain (8.4 dB) on par with that measured by Makhinson (8.0 dB), and an input return loss that indicates a good match to 50 Ω.

Shortly after Makhinson's article appeared in *QST*, however, we received reports that builders who'd carefully duplicated his preamp and post-mixer amplifier circuits from *QST* had been rewarded with *oscillators* instead of the excellent amplifiers he designed! Investigation revealed that a drafting error in the original article's Figure 9, corrected in June 1993 *QST*'s "Feedback" (no pun intended, honest!), had transposed the three- and five-turn windings of T5 and T6 to produce positive feedback.

Modeled in *ARRL Radio Designer* (Figure 3), the miswired circuit produces the eye-opening effect of *positive* MS_{11}—an input return *gain* instead of a return *loss*! In reporting K, the Rollett S-parameter stability factor,[5] for the correct and incorrect circuits, *ARD* confirms what we already know: Built as Makhinson intended, the circuit is unconditionally stable; built with positive feedback, it's highly *un*stable. Oops!

ARD Versus Oscillators Hint Number 1: Monitor MS_{11} and K

In circuits intended to amplify and *not* oscillate, positive MS_{11} values and values of $K \leq 1$ indicate the likelihood of unwanted oscillation. The higher the positive MS_{11} value, and the farther K drops below 1, the greater the likelihood of oscillation.

Finally, a heads-up: Modeled-circuit characteristics that significantly differ from published results or from what you expect may mean misdesign, but they may also signify netlist errors. On the other hand, a circuit that oscillates on the bench *and* models as potentially unstable is a strong candidate for "back to the drawing board"—unless an oscillator was what you had in mind in the first place. In the next "Exploring RF," we'll put *ARRL Radio Designer* to work helping us choose components that (nearly) *ensure* oscillation. See you then!

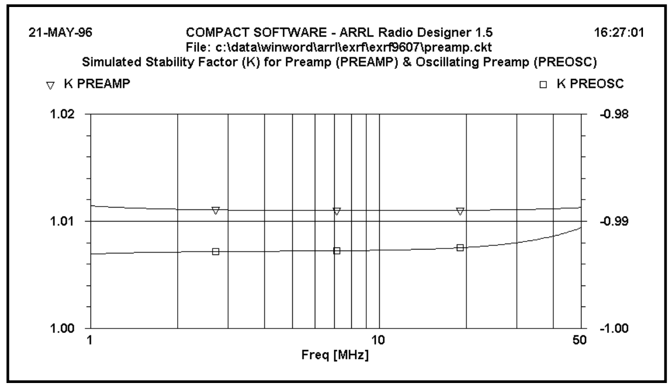

Figure 4—An S-parameter stability factor (K) greater than 1 indicates unconditional stability, and Makhinson's preamp circuit achieves it. With its feedback transformers miswired per the erroneous Figure 9, however, the circuit achieves high *in*stability as indicated by a negative value for K.

Come Visit *ARD* and "Exploring RF" at *ARRLWeb*

You can download circuit and report files for this month's MRF586 preamp oscillation explorations, packaged in the archive file exrf9607.zip, via *ARRL Radio Designer*'s home page (**http://www.arrl.org/ard/**), a subpage of *ARRLWeb* (**http://www.arrl.org/**), the League's World Wide Web service. The file is also available via the ARRL HQ telephone BBS (860-594-0306) and ARRL FTP site (**ftp://ftp.barc.org/pub/hamradio/arrl/**) and its mirrors. Past editions of Exploring RF are available via the Web, too; just check the *ARD* home page's "Articles About *ARRL Radio Designer*" subpage at **http://www.arrl.org/ard/ardarts.html**.

Notes

[1]Available from ARRL for $150 plus shipping as publication 4882. Contact HQ Publications Sales at (voice) 860-594-0250, (fax) 860-594-0303 or (e-mail) **pubsales@arrl.org**.

[2]Jacob Makhinson, N6NWP, "A High Dynamic Range MF/HF Receiver Front End," *QST*, Feb 1993, pp 23-28. Also see "Feedback," *QST*, Jun 1993, p 73.

[3]Wes Hayward, W7ZOI, *Introduction to Radio Frequency Design* (Newington: ARRL, 1994), p 218. Available from ARRL for $30 plus shipping as publication 4920. Contact HQ Publications Sales at (voice) 860-594-0250, (fax) 860-594-0303 or (e-mail) **pubsales@arrl.org**.

[4]David E. Norton, "High Dynamic Range Transistor Amplifiers Using Lossless Feedback," *Microwave Journal*, May 1976, pp 53-57. Also see US Patent 4,042,887.

[5]Wes Hayward, W7ZOI, *Introduction to Radio Frequency Design* (Newington: ARRL, 1994), p 196.