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ARRL Radio Designer as a Learning (and Just Plain Snooping) Tool

After all the heavy-duty transistor modeling stuff I've written for the past several columns, I want to get back to pointing out that the equally big news about *ARRL Radio Designer* is that you don't have to be a Junior Radio Engineer to get a lot out of using it. It's also *fun*, especially if you like just knowing technoidy things about radio. If you can get reasonably conversant with basic radio-design concepts and language—to the point where you know right off the top of your head what resistance and reactance are, say, and the units for and conventions of describing them, and how the reactance of certain types of radio parts changes with frequency—*ARRL Radio Designer* can be a great intuition accelerator. It can make much of the abstract technical stuff you learned in studying for your ham license come alive at your fingertips.

Reactance, impedance and resonance effects are particularly worth exploring with *ARRL Radio Designer* because they're close at hand whenever we do radio. Reactance, remember, is a component's *ac resistance*—and radio is high-frequency ac. A pure, ideal 50-Ω resistance of "looks like" (as we traditionally say) 50 Ω at any frequency. (Any *real* 50-Ω resistor, one you can actually get your hands on, will start looking less and less like a pure resistance as we move higher and higher in frequency because it exhibits some inductance and capacitance. An *ideal* resistor won't—but you also can't buy one.) On the other hand, a component with a *reactance* of 50 Ω can have that particular reactance at only one frequency; at other frequencies, its ac resistance will be different. The reactance of a coil—an *inductor*—increases as frequency rises, and vice versa; the reactance of a capacitor decreases as frequency rises, as shown in Figure 1. By tradition—some prefer to dignify this a bit more and say "by convention"—we say that inductive reactance is positive and capacitive reactance is negative.

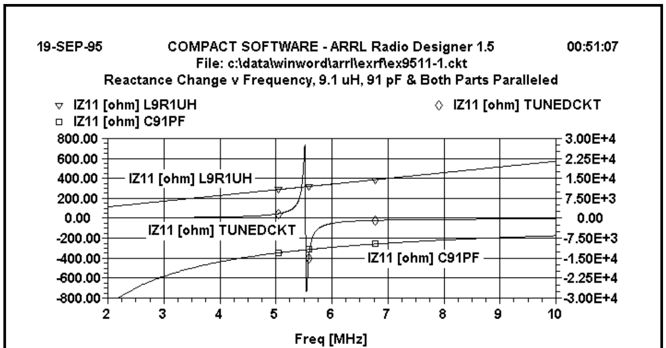


Figure 1—Maybe *you're* so well-versed in radio fundamentals that this *ARRL Radio Designer 1.5* graph of reactance versus frequency for a coil (9.1 µH, as shown by the IZ11 [ohm] L9R1UH trace) and capacitor (91 pF, as shown by the IZ11 [ohm] C91PF trace) isn't interesting, but for many of us, me included, seeing such abstractions come to life on-screen makes *ARD* an untiringly powerful tool for understanding radio's basics. (This graph shows reactance as the imaginary [I] portion of the Z parameter Z_{11} for the coil and the capacitor.) Not only do we get to see—for *any* component values we care to enter, over *any* frequency range we want—how the reactance of an inductor increases with frequency and the reactance of a capacitor decreases with frequency, we also get to see the near-magical phenomenon of *resonance*: what happens when the absolute values of a parallel (or series) coil's and capacitor's reactance are exactly equal. For a 9.1-µH coil and a 91-pF capacitor, that condition occurs at just over 5.5 MHz. At resonance, the reactance of the paralleled parts is *zero*, and together they act as a pure, high resistance.

Figure 1 also shows the reactance versus frequency of a coil and capacitor connected in parallel. At the frequency at which the absolute values—the numeric parts, regardless of sign—of their reactances are *exactly equal*, they *resonate*. At this frequency—just above 5.5 MHz for the 9.1-µH and 91-pF parts used in the Figure 1 simulation—they exhibit a high resistance, and no reactance at all. Immediately above and below resonance, their reactance shifts wildly. Above resonance, they act as a capacitor; below resonance, as an inductor. This may be old hat if you've long had your radio fundamentals well in hand, but it's fascinating—and part of the soul of radio—nonetheless. Figure 2 expands on this by showing the resonant circuit's resistance *and* reactance. Yes, resonance is a strange and wonderful thing. Just go and watch that old film clip of the wind-excited Tacoma Narrows Bridge one more time!

Viewing the phenomenon of resonance with unjaded eyes can lead to some pretty interesting circuit tricks. For instance, the fact that a paralleled coil and capacitor can act as a coil (below resonance) and a capacitor (above resonance) with reactance-versus-frequency characteristics that significantly differ from an actual coil or capacitor acting all by its lonesome—compare the slopes of the three traces in Figure 1!—can be quite handy if carefully applied. Charles J. Michaels, W7XC, used this characteristic in his April 1992 Hints and Kinks piece, "A Load-Tracking **L** Network" (Figure 3).

Figure 4 shows a circuit, described by Warren Bruene, now W5OLY, in Chapter 18 of Keith Henney's *Radio Engineering Handbook*, fifth edition, that takes advantage of this effect in another way. (Sure, the original circuit used tubes, but I modified the drawing so today's solid-state purists won't glaze over in disdain and miss an interesting idea.) In parallel-resonating to peak Q1's output at 7.1 MHz, L1 and C1 also *series*-resonate with C2 to shunt 3.55-MHz energy to common. In other words, L1C1

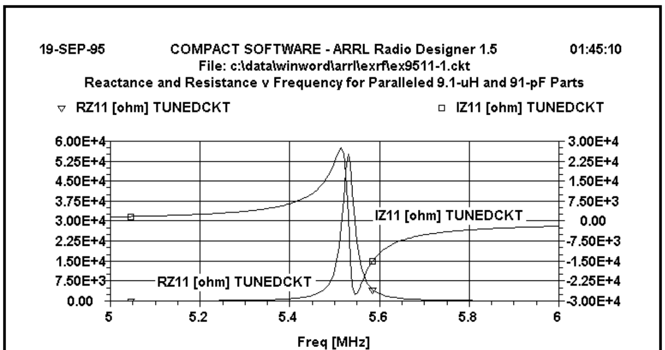


Figure 2—As their summed reactances do a wild dance around and through resonance, a paralleled inductor and capacitor exhibit a resistance that rises to a high peak right *at* resonance.

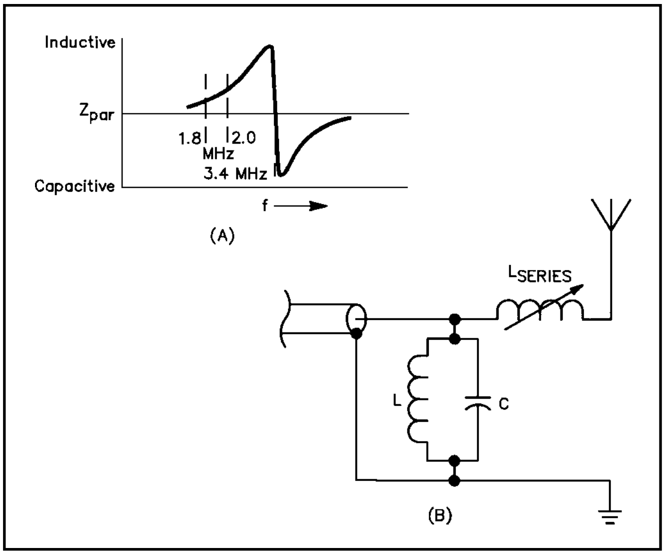


Figure 3—In a region far below resonance, where it's still inductive, the impedance-versus-frequency curve (A) for a parallel LC circuit approximates just the characteristic W7XC needed to track his antenna's impedance-at-resonance curve. Charlie Michaels configured the resulting network (B) by adjusting L and C for a match that provides an SWR of 1.4 or less from 1.8 to 2 MHz with L_{SERIES} adjusted for minimum SWR (1:1 at 1.94 MHz). In his case, L and C resonate near 3.4 MHz. (from Charlie's "A Load-Tracking **L** Network," April 1992 Hints and Kinks)

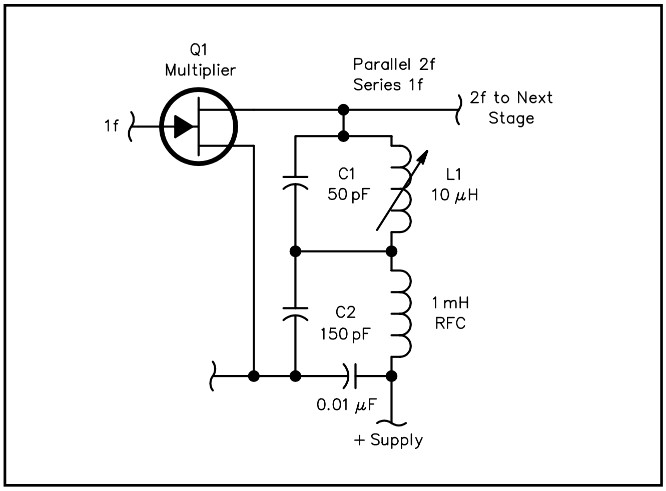


Figure 4—Just suppose you had a single-transistor frequency multiplier stage that you drove with 3.55-MHz energy to get 7.1 MHz output. If you just peaked Q1's drain with a tuned circuit (L1 and C1), you might get enough rejection of the 3.55-MHz fundamental at Q1's output, and you might not. If, however, you installed C2 to series-resonate L1C1's reactance at 3.55 MHz, you'd short-circuit much of any 3.55-MHz feedthrough to ground. The 1-mH RF choke is there to let dc flow around C2—but it has another effect, as Figure 5 shows.

and C2 form a series-resonant *trap*.

Figure 5 shows how the Figure 4 circuit performs when we look across it as a two-port network and tell *ARD* to evaluate its forward transmission gain in decibels. (The logarithmic nature of the decibel scale lets us see more wide-range detail than the linear scales we'd have to use in evaluating the network's reactance, resistance or impedance.) We see the dip (at 3.55 MHz or so) and peak (at 7.1 MHz) we expect. We also see that the 1-mH RF choke gives rise to a strong resonance just above 400 kHz—something we may not want if Q1 or the subsequent stage has enough gain at 400 kHz to oscillate or regenerate. *And* we get an idea (from the MS21 [dB] PARNOTRP trace) of the improvement in subharmonic (fundamental)-signal rejection to be gained by this technique, compared to just letting L1 and C2 do the job on their own.

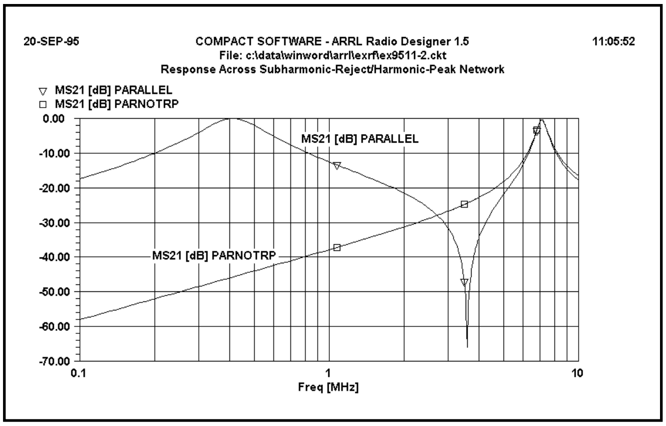


Figure 5—Well, looky here! As we expect, we see a significant peak at 7.1 MHz (where L1 and C1, Figure 4, resonate). We also see a deep dip near 3.55 MHz, where C2's reactance series-resonates with that of the L1C1 tuned circuit. The Figure 4 circuit would therefore do what we want: Peak signals at 7.1 MHz and dip signals at 3.55 MHz. But it turns out that our 1-mH RF choke isn't as benign as we thought: It parallel-resonates (through the 0.01-µF bypass capacitor) with C2 to make a strong peak near 400 kHz. Old-timers who've toiled long at the workbench trying to rid a vacuum-tube transmitter of *low-frequency parasitics* can regale you with horror stories about the hassle such hidden low-frequency resonances can cause. The MS21 [dB] PARNOTRP curve lets us compare what the 7.1-MHz L1C1 circuit would do on its own without the extra resonances added by C2 and the RF choke.

Using ARD to Snoop in Commercial Gear

Anyone who's paid much attention to the technical pages of *QST* for at least the past half-decade or so will probably roll their eyes when I yet again characterize myself as a receiver snob. But we spend most of our on-air time *listening* and relatively little of it transmitting—so we owe ourselves receivers we can not only stand to listen to, but *like* to listen to, for long stretches. A recent pair of *QST* articles by Jukka Vermasvuori, OH2GF—"Hot-Rod Your ICOM IC-725-Series Transceiver," in September and October 1995 *QST*—was music to my ears in this regard because Jukka went to considerable lengths to improve, among other things, the receive sound of the popular IC-725. I consider it quite instrucitonal—not to mention great fun—to let *ARRL Radio Designer* confirm what Jukka found and fixed in the IC-725's audio chain—to prove yet again that if you can read a schematic and spend a few minutes typing simple alphanumeric gorp into *ARRL Radio Designer*'s ASCII netlist editor, you can find out (or confirm) some quite interesting things about why your radio sounds the way it sounds. To that end, Figure 6 repeats OH2GF's schematic of the IC-725's audio chain, this time with node numbers added for *ARD* netlisting. Figure 7 shows *ARD*'s simulation of the audio chain's frequency response before (UNMOD) and after (MOD) OH2GF's modifications. Need I say which one *I'd* rather listen to? The not-so-hidden message here is that if you can simulate it, you can also safely and reversibly tweak it and improve it *long before you ever warm up your soldering iron* to go to work on the real thing.

Internet Extensions to *ARRL Radio Designer*

This is where, in previous columns, I'd cut loose with the

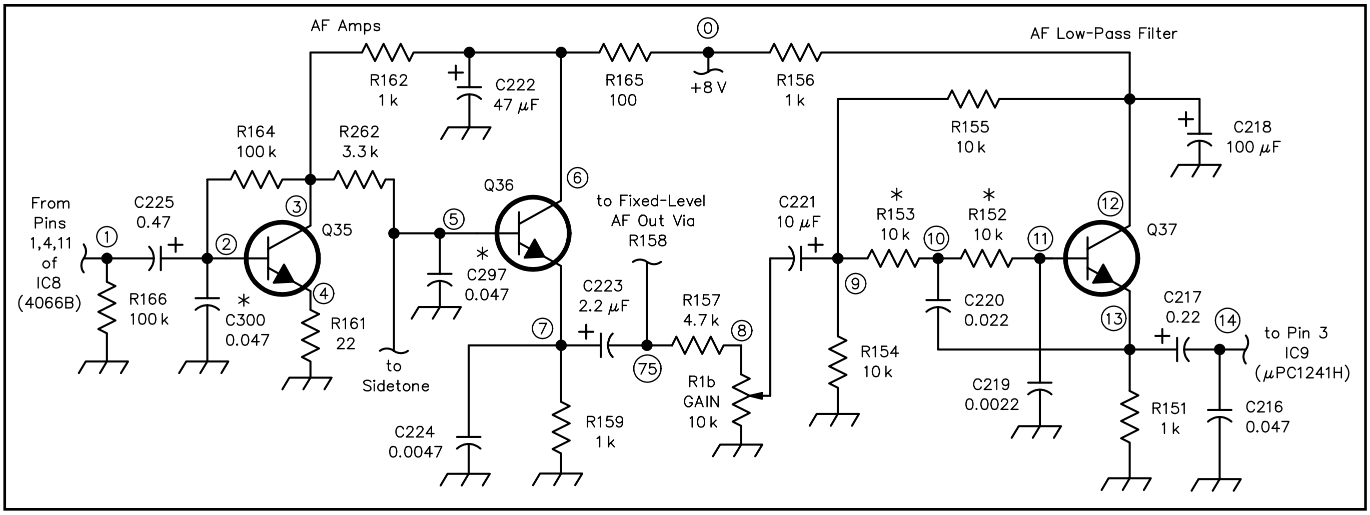


Figure 6—The IC-725's audio amplification chain includes significant rolloff to tame IF hiss and 7-kHz leakage from the radio's digital circuitry. Modifying these stages for better performance involves changes to the asterisked components as described by Vermasvuori, OH2GF, in September 1995 *QST*.

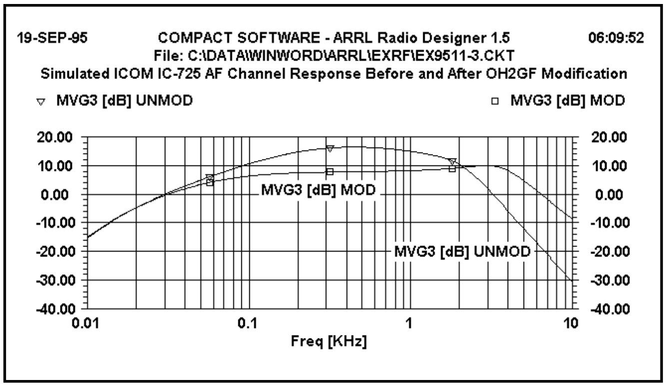


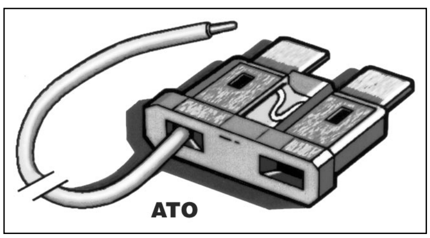
Figure 7—*ARRL Radio Design's* simulation of the IC-725 audio chain's frequency response—modeled with the wiper of the radio's **AF GAIN** control all the way up from ground—before (UNMOD) and after (MOD) OH2GF's modifications.

subhead **Free Electronic Goodies**—but talk about old hat! By now you've probably heard about *ARRLWeb*, the League's new HQ-based World Wide Web site at the URI **http://www.arrl.org**. *ARRLWeb* extends *ARRL Radio Designer* in the sense that it includes a link to *ARD*'s own home page (**http://arrl.org/ard/ardpage.html**) and the *ARD* FTP site (**ftp://arrl.org/pub/ard/**), from which a file containing circuit and report files for all of this month's column's simulations, exrf9511.zip, is freely available. The *ARD* home page extends what there is to know about *ARRL Radio Designer* in a number of ways—news, tips and files; a glimpse of how *ARD* looks when running under *Windows 95*; and how to subscribe to ARRLCAD, the mailing list devoted to *ARD* and other Amateur Radio CAD packages and topics. There's even a link to Compact Software (**http://www.comsoft.com/**), the developers and programmers of *ARRL Radio Designer* and its superset, *Super-Compact.* We're committed to making increasing use of the vast tool called the Internet, specifically the World Wide Web, to enhance the utility of *ARRL Radio Designer*.

QST

New Products

PIGTAIL AUTOMOTIVE FUSES



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