This is a copy of a recent post to the on-line discussion group devoted to our book Experimental Methods in RF Design, hosted by Roger Hayward. It is posted here in response to several questions regarding JFETs and the common gate topology in my current ECE521 Analog IC Design Class.

Rick Campbell

The common gate amplifier has been one of my favorite topologies since the mid-1970s. My designs have been at audio through microwaves, and I have gone through a bag of 100 U310s and approximately 200 J310s, mostly in different and new prototype designs. The J310 is one of the most stable and trusted components in my repertoire, and the common gate amplifier one of my most repeatable and trusted topologies.

But there are some basic guidelines to follow. I've used the J310 for amplifiers and oscillators from audio through about 500 MHz, and the U310 from audio through 600 MHz. So here's the first bit of wisdom, straight from Barrie Gilbert:

The transistor doesn't know what it's supposed to do.

If you are building an audio amplifier with a transistor that can also work as an oscillator at 600 MHz, you can't use 12AX7 vacuum tube audio construction techniques with long leads to a single point ground. Examine every physical circuit (not simulation!) at the highest frequency at which the transistor has gain. Bypass capacitors with leads aren't particularly effective above a few hundred MHz, and tuned circuits in my 600 MHz oscillators are less than an inch of straight wire. If your PC board layout has an inch of wire between the J310 and the next components, it may well oscillate at 400 MHz or so.

Common Gate means exactly that. If you can see the gate lead, it's not common gate--it's "inductor in series with the gate."

The U310 is in a metal can, with the gate attached to the can, and was designed to be soldered into a hole in the circuit board ground. A strategy I've used for years with HF through UHF amplifiers is to drill a hole for the J310 plastic body, drop the transistor in the hole with the leads up, and then solder a tin shield across the hole, with the source lead on one side, the drain on the other, and the gate lead soldered to the shield. That works every time and is certainly not original with me. It was a standard technique in the 1970s when I first started using J310s and U310s in VHF and UHF projects.

The voltage gain of a common gate transistor from source to drain is roughly equal to the impedance driven by the drain divided by the impedance that drives the source. So a common gate J310 driven by 50 ohms and connected to a 500 ohm load has a voltage gain across the device of about 10. But in order to connect the drain circuit to a 50 ohm load, you need to step the impedance down by a factor of ten, using the equivalent of a transformer. At audio, we use actual transformers. At RF we often use a Pi Network. In either case, the impedance transformation is 10:1 and the voltage step down is the square root of that, or 3.16:1.

The gain in dB from 50 ohm input to the 50 ohm output is 20 log Vout/Vin, so the power gain of the above common gate amplifier (20 log 3.16) is 10 dB.

When I design VHF and UHF common gate amplifiers, I usually do a quick back-of-the envelope calculation to come up with pi-network components for a gain of 10 dB. At HF sometimes I go as high as 13 dB. More precise analysis with all the transistor variables would yield a gain of about 9 or 12 dB for those two cases, but the math detail obscures the basic underlying circuit operation. It's more enlightening to design for a gain of 10 and expect a little less. The published component values in my designs are usually taken straight from the finished and working circuit on the bench. If your simulation shows a gain peak of 6.8 MHz using values that I found to work at 7.1 MHz on the bench, spread the turns a little on the toroids in your simulation. Oh wait, you can't do that--it's a simulation. Hence, a bit of wisdom from Wes Hayward:

The simulation is the greater experiment.

Engineering professors and their students place great faith in circuit simulators, but engineering professors who have actually designed, built, and measured anything are becoming rare. If you know some, treasure them.

Because of the size of components such as variable capacitors and toroid inductors, the source and drain leads can't be as short as the gate lead. Keep them as short as is practical and as far apart as possible. The source circuit is low impedance, so electrostatic coupling is less significant than in the drain circuit. If the drain circuit is a tuned Pi-Network, divide the total needed capacitance into a fixed cap as close to the drain as possible and a variable a convenient distance away. In PC board layouts with modern components, it is worthwhile to use a chip capacitor. Remember the J310 is a UHF component, even when we're building a 40m rig.

Remember: The transistor doesn't know what it's supposed to do.

Now, what about that 22 ohm resistor in series with the drain lead? In the 500 ohm drain circuit it clearly doesn't do much at the signal frequency. But the drain lead, capacitor frame, and wire leading into the pi-network inductor may easily have some resonant behavior up in the UHF range. If so then it may oscillate. So the 22 ohm resistor is a simple VHF suppressor, just like is connected to the plate cap on top of virtually every tube PA ever commercially built. Those parasitic suppressors became common in vacuum tube circuitry as soon as tubes had gain above 30 MHz. A 22 ohm chip resistor is ideal.

Regarding circuit simulators and other video games. I admit, I spend a lot of enjoyable time designing circuits in a simulator. I also spent nearly a decade as a professional RF and Analog simulator driver--that was more work than fun. But a simulation is not a radio. It isn't even a circuit, or a single transistor. It's just a model. It may be a very expensive model, like on Project Runway, but it isn't reality. Use the simulator as a tool, like a soldering iron. You could use a soldering iron to draw your circuits on a breadboard--but that isn't the best use of the tool. Develop a sense of when to turn off the simulator and warm up the iron, and vice versa.

In 1992 I developed a set of Direct Conversion Receiver and Exciter modules that have been widely duplicated and used as the basis for a number of modern commercial rigs. The following comments refer to that set of modules and some follow-on work that is currently published in the Handbook for Radio Communications, published by ARRL.

The original R2, T2 and miniR2 were designed entirely using classic engineering circuit analysis, taped-by-hand layouts, and measurements of the resulting bench prototypes--no simulators. The toughest part of the design was cramming all that high gain circuity on a small double-sided PC board with stability and signal integrity, and the simulator doesn't yet exist to successfully do that.

The first of my designs that really benefitted from simulation was the R2pro. But the first attempt to build that all on a single PC board failed, so I divided it up into 5 functional PC blocks. As soon as I did that, I was able to make a number of significant performance enhancements, and since then have resisted all pressure to do another single board high-performance direct conversion receiver. Modular construction works, and is both easier and almost alway higher performance than a single board approach.

The microR2 was designed with help from a simulator after carefully studying everything in Chapter 8 and 9 of EMRFD. By far the toughest part was getting a stable layout, but I took that on as a design challenge and the resulting receiver came out nicely. The J310 RF amplifier and LO were never a problem. Newly manufactured 2N3904 transistors will oscillate above 300 MHz. That means you can't treat garden variety NPN transistors like HF and audio transistors anymore either.

Finally, a word about ugly construction. Yes, of course it works--but remember that the origin of the term comes from a project Wes Hayward did at his famous bench with his son Roger. Wes understands more about parasitic inductance, capacitance and RF layout than most RF designers, and had read and absorbed just about everything written in the RF Design literature for two decades by then. If you examine his ugly circuits, you will find that the leads that need to be very short are very short, and the ones that can be--or need to be--long are long. Under it all is an unetched ground plane, and particular attention should be paid to how he treats the leads soldered to that. So ugly construction is quick and works exceptionally well--usually significantly better than the first attempt at a printed circuit board--but it is a "thinking person's" construction technique. This was and remains of no concern for Wes--he assumes that every designer has moving parts until proven otherwise.

These days a lot of beginning designers expect to go straight from the simulator to a working circuit, with the brain switched off. But simulators are full of things that don't exist in nature: wire, ground, and voltage-source power supplies for example. So you need to think about which wires need to be zero length (they all are in the simulator), which grounds need to be zero inductance and resistance (they all are in the simulator) etc.

My schematics are in the public domain, but I put a copyright symbol on most of my printed circuit board artwork. They are art and I recommend that you study them, with particular focus on what is short, what is long, how ground is treated, how power supply leads are treated, and how components with UHF gain are handled in the layout. Becoming a successful radio designer is a little science, a lot of engineering, and a significant amount of art, and there are different learning techniques for each. For art, the time honored method is continuing study of other people's work and practice on your own creations. You will get better with time. Your 20th project will look better and work better than your first or second, so it is critical that you get off the simulator and get to the bench and start building and measuring your designs.