07 July 2005

A wrong turn

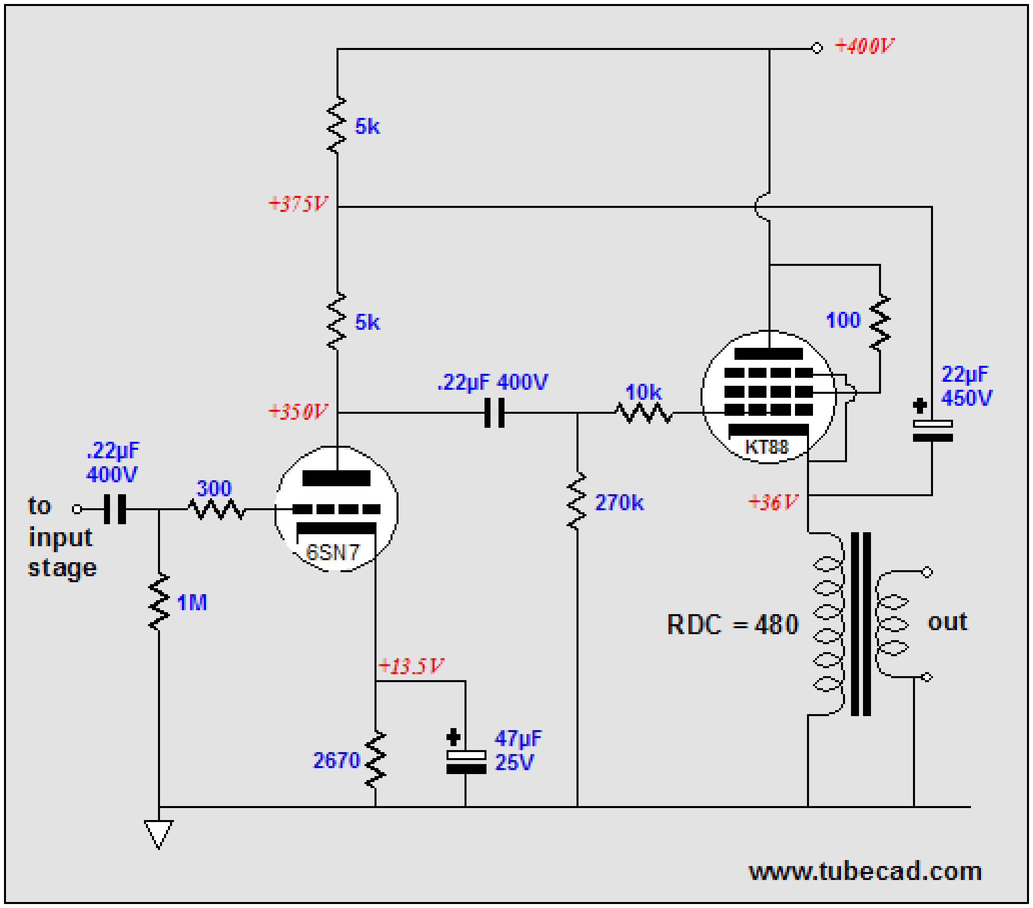
A cathode-follower output stage can excel, but only if it is given a pure input signal—a very-large pure input signal. Yes, indeed, the problem of giving the output stage the required drive signal is a big one: for what shall it profit a man, if he shall gain the lowest distortion output stage, but loses the driver stage's integrity? Verily. Remember the output tube(s) grid must see a signal larger than the cathode will swing: the inverse of the cathode follower's gain, in fact. Thus, a cathode follower gain of 0.9 would require a grid signal that is 1.11 times larger that the desired cathode swing; for example, 111V peak volts in for 100V peak volts out, 222V peak-to-peak for 200V peak-to-peak.

The output stage has the advantage of working into an inductively-coupled load, so it can swing its cathode(s) far bellow ground, as if there were a negative power supply equal to the positive power supply; the driver stage tube is seldom so lucky. For example, in this example, the output stage's B+ voltage might only be 150V. Now, do we fit 222V of peak-to-peak voltage swing into a 150-volt B+? We don't...not without cheating.

Cheating?

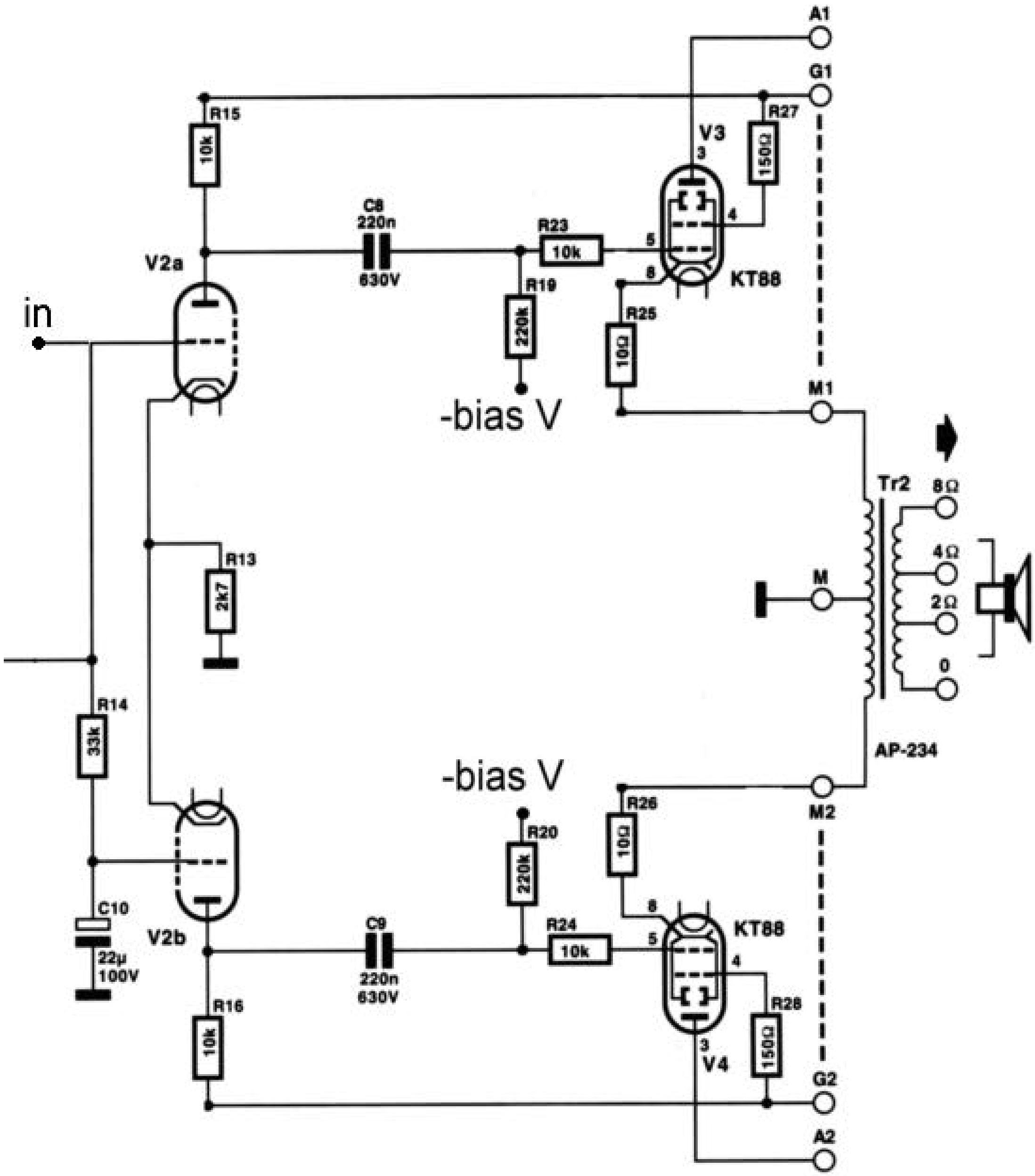
What devious circuit designers try to do is to cheat the system by using some form of bootstrapping: the process of feeding the output stage's voltage swing back into the driver stage, so that the output stage ends up driving its own grid. By bootstrapping the driver stage, they hope to get everything they want—low B+ voltages, high gain, low distortion, and low output impedance—without having to pay for it; unfortunately, in vain. (The word "bootstrapping" paints the picture of a man trying to lift himself off the ground by pulling up on his own boots' laces, also in vain.)

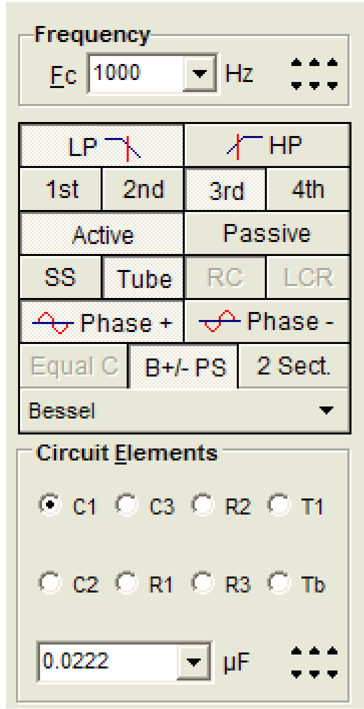
Ultimately, bootstrapping a cathode follower's driver stage is just the implementation of positive feedback, which means that the output stage no longer enjoys cathode follower's 100% degenerative negative feedback, which means that it no longer acts as a cathode follower, working instead like a grounded-cathode amplifier. Positive feedback, in contrast with negative feedback, increases gain, distortion, and output impedance. Amazingly, few tube gurus understand this, because the visual features of this topology prevail over the actual inner functioning of the circuit: if it looks like a cathode follower, it must be a cathode follower. (The makers of cubic-zirconium jewelry wholeheartedly endorse such logic.)

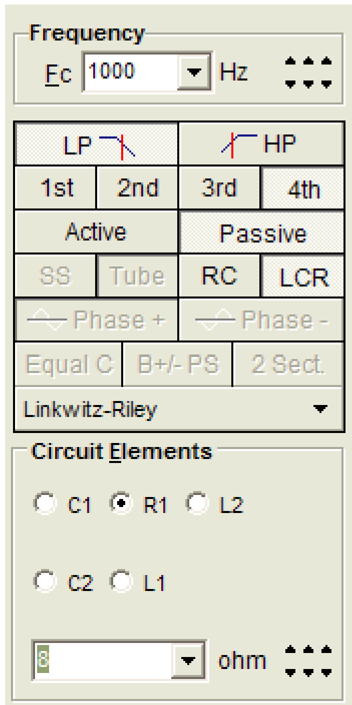


Bootstrapped driver stage

In the circuit above, we see a bootstrapped, single-ended, cathode-follower output stage. Note the shared B+ voltage and the small driver stage plate resistor value (5K). Now a 6SN7-based grounded-cathode amplifier loaded with a 5k plate resistor and a unbypassed cathode resistor could only realize a gain of about 2 or less; yet when used in a bootstrapped configuration, the gain can easily equal something close to the tube's mu. (The closer the cathode follower's gain is to unity, the greater the driver tube's plate resistance magnification, but the less cathode follower action obtained from the output stage; for example, if the cathode follower's gain were 1, then its grid would effectively be "grounded" to its cathode.) I was about to go further into the inner workings of bootstrapping when I remembered that I had already covered the topic in the *Tube CAD Journal,* at least twice. To read more on bootstrapping, follow this link . Read this page and the page after. (I'll be immodest here: I wish I had the *Tube CAD Journal* to read 25 years ago when I began to study tube electronics in earnest. It would have saved me hundreds of hours in musty library stacks, peering into old books and journals; and countless hours soldering together circuits, testing, evaluating, and burning a finger or two.)

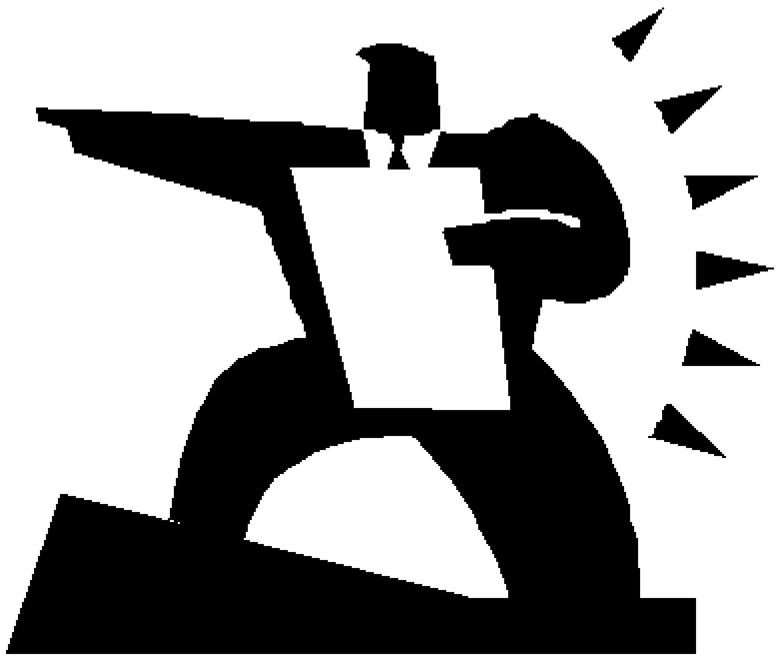






The Tube CAD Journal's first companion program, TCJ Filter Design lets you design a filter or crossover (passive, solid-state or tube) without having to check out thick textbooks from the library and without having to breakout the scientific calculator. This program's goal is to provide a quick and easy display not only of the frequency response, but also of the resistor and capacitor values for a

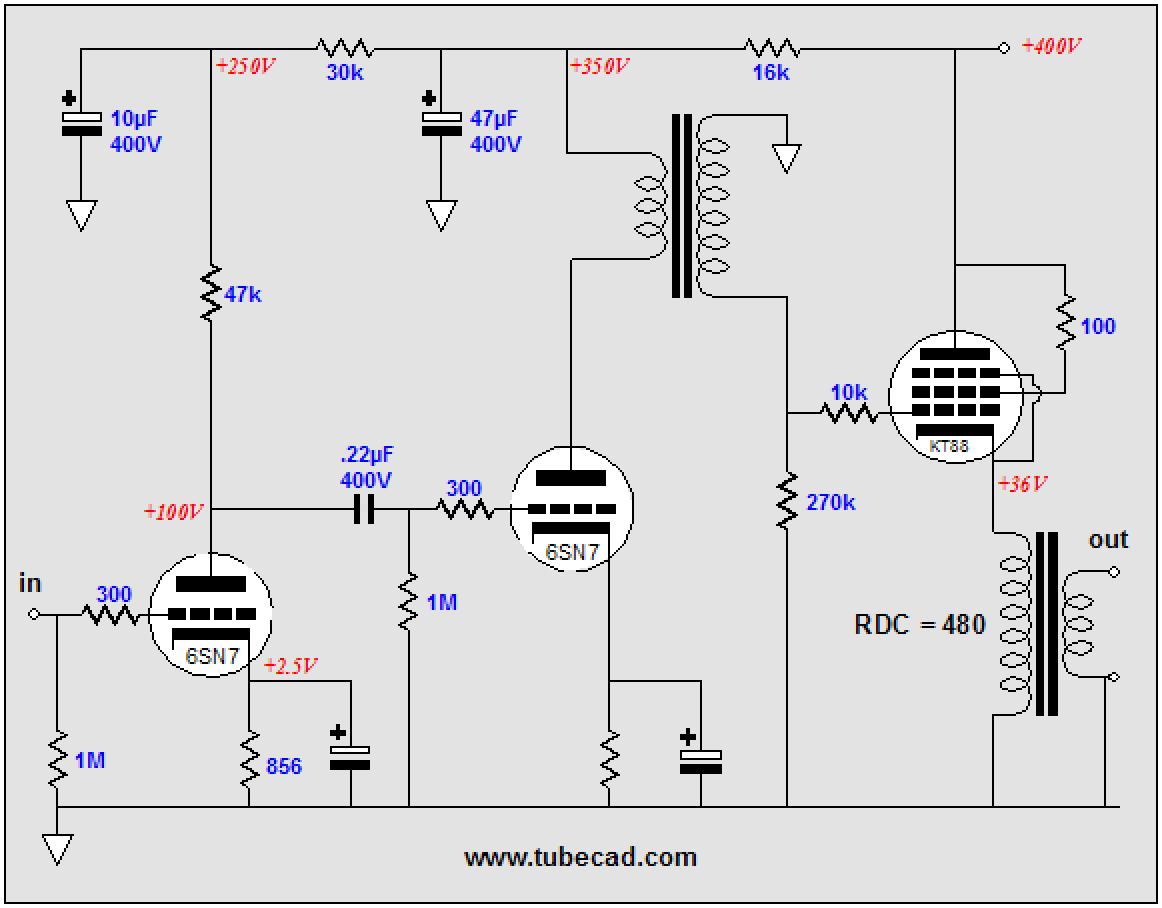
The May 2001 issue of the great international electronic magazine, *Elektor Electronics,* held an interesting amplifier output stage design, which is shown above. There is so much that I like about the article—it refers to the circltron topology that the amplifier uses as the "parallel push-pull," for example—that I feel bad about sending a large torpedo it way. The claim made is that this version of the circltron/parallel amplifier uses output tube in a cathode-follower configuration; it doesn't. The dashed lines represent well-filtered, floating power supplies. These power supplies ensure that the pentode's screens are tightly locked to the swinging cathodes and they also directly connect to the driver stages plate resistors, which undoes all the cathode follower attributes, as the bootstrapping relays any disturbance at the output cathodes right back to the output grind in phase, not anti-phase.



Legitimate short cuts

Since the driver stage must put a peak-to-peak output voltage swing in excess of the output stage's B+ voltage, we can either give the driver stage a higher B+ voltage (two to three times higher) or use an inductive component such as a step-transformer or choke plate load to get the big voltage swing into a smaller B+ voltage.

A step-up transformer can perform a miracle of sorts: it magnifies its input signal by its winding ratio; 1Vac goes in and 10Vac—or even 100Vac—comes out. But as the transformer also strictly abides by the laws of physics, we still have to pay for our lunch. True, the input signal was increased by the winding ratio, but the input impedance presented at the transformer's primary is also decreased by the square of the winding ratio. Thus the output tube's grid resistor's value is reflected to the transformer's input as a much more severe load, as it is effectively decreased by the square of the winding ratio, so a 400k grid resistor will be reflected as a 1k resistor by a 20:1 step-up transformer. Of course, if the secondary is directly attached to the cathode follower's grid without a grid resistor shunting the winding, this concern does not apply—until the grid is driven positively relative to the cathode follower's cathode that is! (Once the grid becomes positive relative to the cathode, the grid and cathode define a forward-biased diode and goes from not conducting to conducting heavily.)



Transformer-coupled

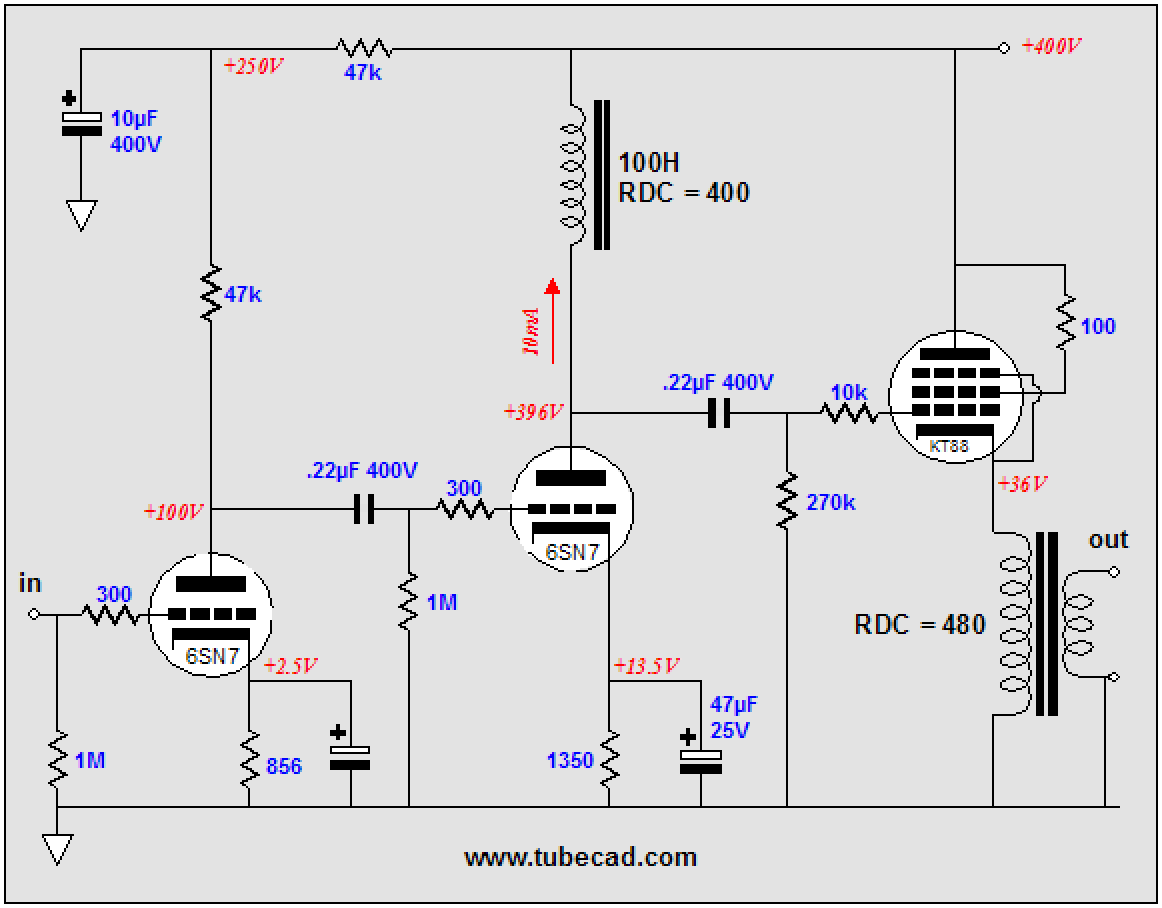
In addition, the input capacitance that the secondary connects to is effectively reflected to the transformer's primary by the same square of the winding ratio, so 15pf can equal 150pf or 1,500pf at the primary. Luckily, a cathode-follower output stage exhibits a much lower input capacitance than does a grounded-cathode amplifier output stage, as the cathode follows the grid and the grid-to-plate capacitance is not magnified by inverted gain at the plate.

Furthermore, adding an interstage transformer to amplifier makes adding a global negative feedback loop at least difficult, if not dangerous, due to the phase shifts that a transformer would introduce. In other words, a step-up transformer could be a godsend, but real-world impurities may prove too burdensome to overcome. In other words, no free lunches whatsoever.

Choke/inductor plate loads allow us to retain the single B+ voltage for both driver stage and output stage. Just as the output stage has the advantage of working into an inductively-coupled load, which allows it to swing negatively well bellow ground potential, the inductor plate load allows the driver stage to swing well beyond the B+ voltage. An ideal inductor would displace none of the B+ voltage; real inductors made from thin wire do displace some of the available voltage. Still, the DCR seldom exceeds 1k, so not that much voltage will be lost to due to the driver stage's idle current against the inductor's DCR. The inductor must have enough inductance to allow low frequencies to be amplified by the driver tube. The formula is:

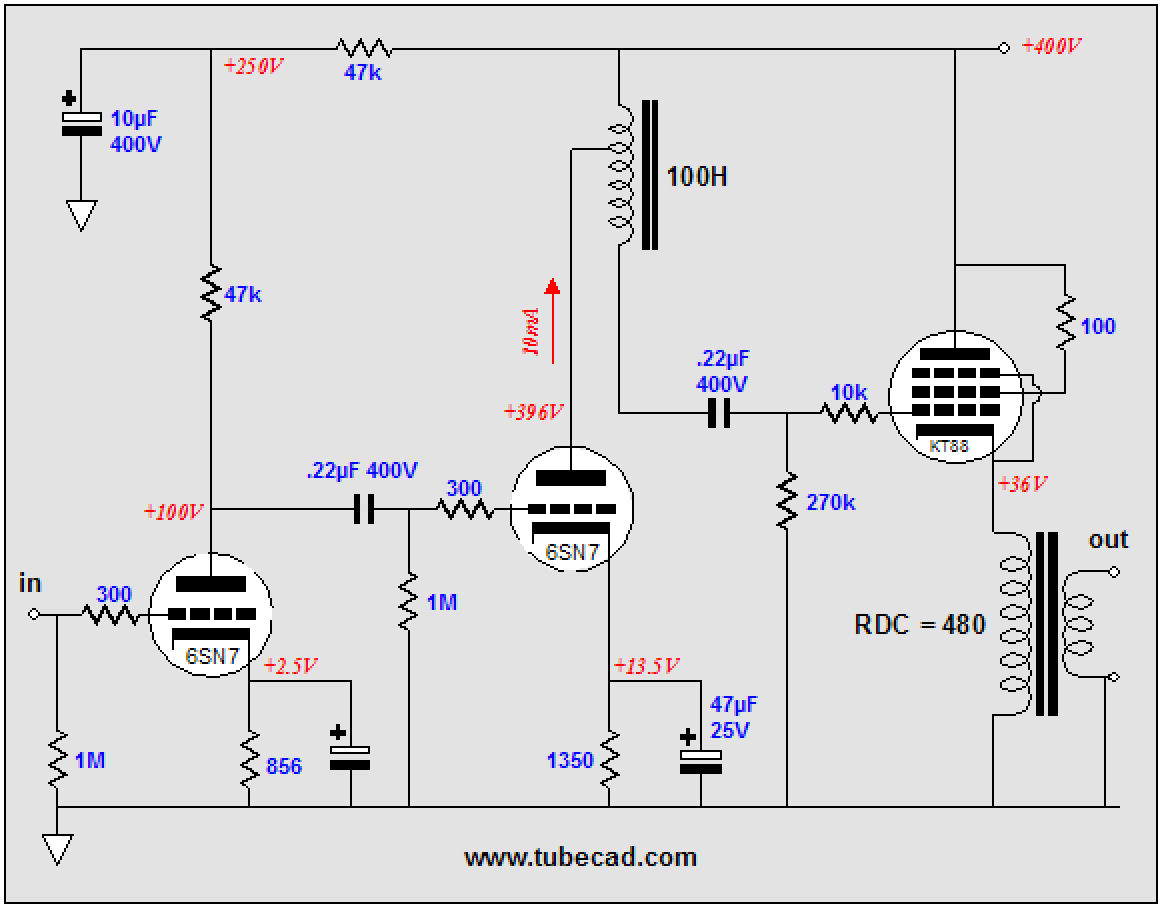
H = R/(2·pi·Frequency)

In this case, R equals the driver triode's rp in parallel with the output tube's grid resistor when its cathode resistor is not bypassed, and [(mu + 1)Rk + rp] in parallel with the output tube's grid resistor when it isn't bypassed. H stands for henrys, not millihenrys.



Choke load

A component that falls in between a transformer and a simple choke is the tapped choke. This inductor holds at least one tapping point in the coil and it allows the choke to provide a step-up function, much like the step-up transformer does.



Center-tapped choke load

Next time

We will cover resistor-loaded drivr stages.

//JRB