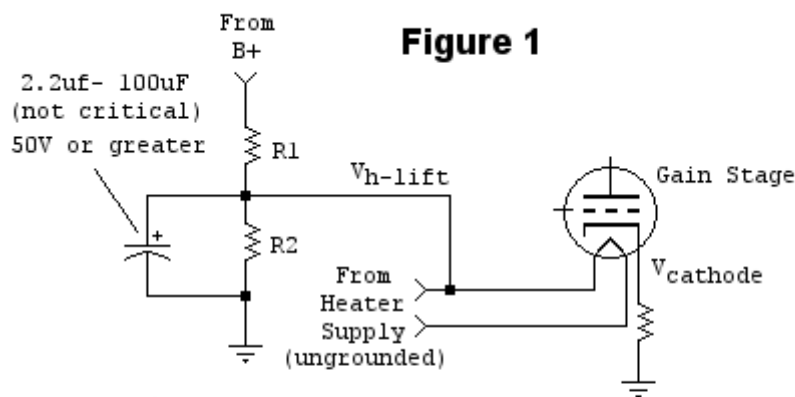


The Underappreciated Hybrid Mu Follower

Anyone who has used the mu follower topology and likes it, must also understand one of the frustrations with the circuit is the heater supply for the top tube.

Why is this a problem in the first place? Well, I can think of two reasons... hum suppression of the heater supply and heater to cathode breakdown potential.

One of the tricks to suppressing hum on the heater I like to use is to lift the heater to some positive potential above the cathode potential (Figure 1). That is no real problem where the cathode is near ground, but when one cathode of a dual section tube is floating higher up in the sky, raising the heater voltage to where the top heater is above the cathode may inadvertently cause heater cathode breakdown of the bottom tube.



Adjust R1 and R2 so $(V_{h-lift} - V_{cathode})$ is between +20 and +40V.

R1 should be between 220K and 470K and 2W to 5W and rated for the full B+ voltage for safety against breakdown.

This unit can also double as a HV bleeder

With a lower high voltage power supply, this isn't a big issue, since the cathode of the top tube is typically held at $B+/2$ and with a low voltage B+ (as is typical with the ECC88, etc.), the top tubes cathode may only be 100V off the floor. So if we put the section of the ECC88 with the 50V h-k breakdown on top and the section with the 150V h-k rating on the bottom and then raised the heaters to +120V, we are within the ratings and have 30V of headroom.

That's all well and fine for low B+, but what about other tubes and higher B+? I've seen some 6SN7GT mu followers running at 600V! Well, there's three ways you can approach this and two aren't particularly safe under some circumstances:

- 1) Use two tube sets, one for the bottom and one for the top and use dual heater supplies, each so their respective heaters are about +20V to +40V above ground or...

2) Use a DC supply and float the heaters or...

3) Use an AC supply floating and bypass it to ground through a capacitor for any riding noise.

#3 is the one most seen in commercial equipment (Dynaco comes to mind) and #2 is used in some kit phono stages.

Under some circumstances, neither #2 or #3 are particularly safe, because the top tube and bottom tube's Vh-k rating while summed, can be still exceeded in the output voltage swing and ***POOF!***, you have a short circuit. One indication Vh-k breakdown is crackling in the circuit like a dirty tube socket, but wiggling the tube has no effect.

There's one way to cure the problem... get rid of that top tube all together. But how do we do this without sacrificing performance of the topology?

Cue the MOSFET

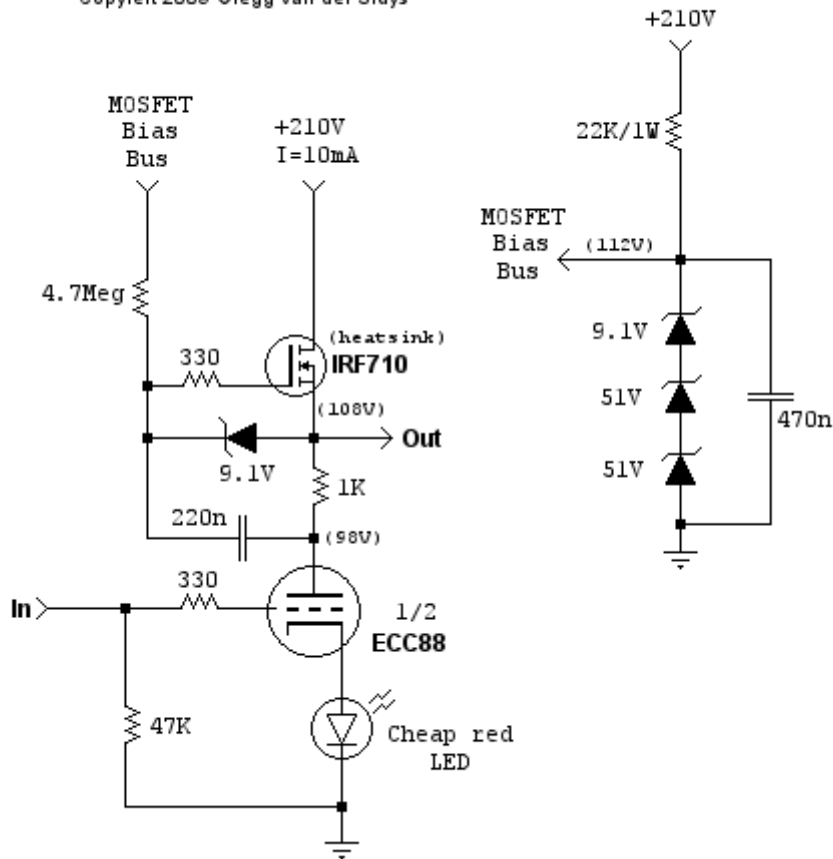
Alan Kimmel had a great idea that he left us in his notes. Check out a copy of his whitepaper [here](#). Take a look at Figure 5 in that link and the surrounding text.

Though it seems most example projects on the net relate to headphone amplifiers and the odd linestage, I've been doing some experimentation with this, particularly in the area of low level and cascaded hybrid mu follower stages.

Here is an example of a hybrid mu follower using an ECC88 and taking advantage of its high transconductance by keeping bias at 10mA:

Hybrid Mu-Follower

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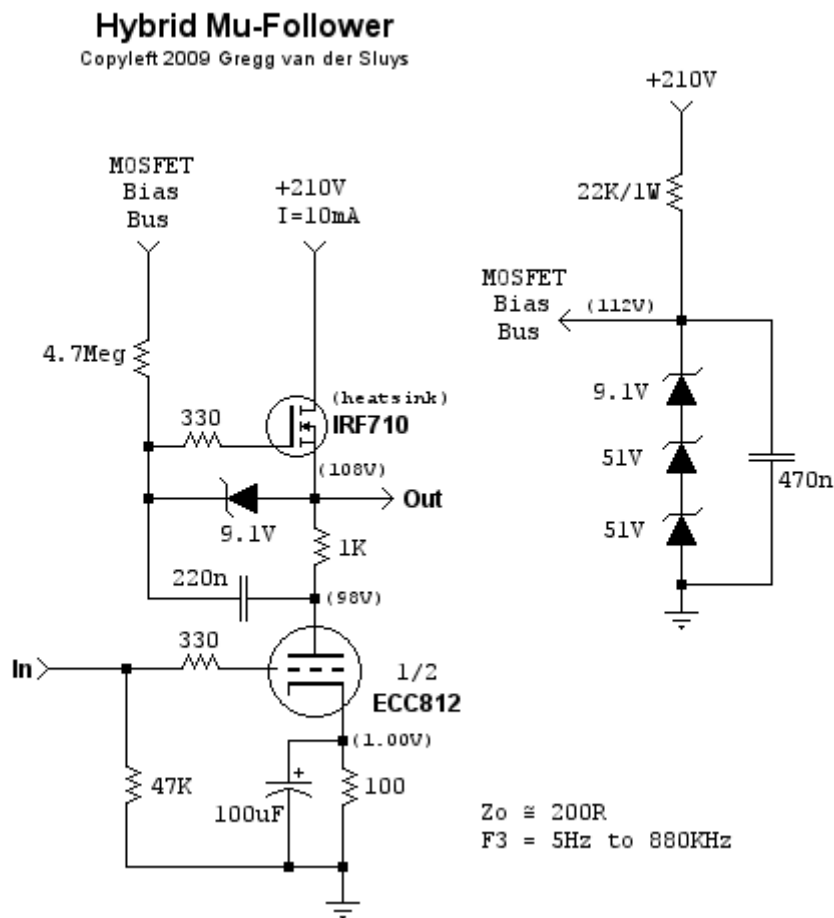


Depending on the health and brand of ECC88 used, it'll draw between 9 and 15mA - within rating of the tube.

In this circuit, I use a fixed voltage for supplying bias to the MOSFET. There are some good reasons for that.

- 1) A fixed voltage on the gate makes the unit act CV, meaning the voltage on the bottom tube is going to see a stable supply, hence stable current flow regardless of B+.
- 2) The above reason also makes this circuit have really good power supply noise rejection. Therefore, you can use a simpler power supply.
- 3) You can have many MOSFET's fed from the one bias supply.
- 4) You can easily control bottom tube bias points with the MOSFET bias voltage and bottom tube cathode resistor.
- 5) With appropriate voltage MOSFET, you can add low voltage or voltage sensitive tubes to an existing amp with high voltage supply circuit.

I also explored this circuit with a high gain, low noise tube, thinking about phono stage possibilities:



I did some actual measurements you see in the schematic. The output impedance is really low with a MOSFET on top, compared to a tube. Bandwidth also is pretty fabulous.

Due to the reasons given in the Kimmel paper, the mu of the bottom tube is used to its fullest extent practical. The book says an ECC812 $\mu = 50$. The measured mu of the above circuit was 49.5 (likely I got my mitts on a "hot" tube though).

As also mentioned in the Kimmel paper, the hybrid is somewhat sensitive to the MOSFET used - only low capacitance gate types should be used. Large gates like the IRFP240, need not apply. This is for a couple reasons:

- Stability. Though the MOSFET is used as a follower, they do make pretty good VHF RF oscillators. Small gated MOSFETS can have these tendencies snubbed with a simple gate resistor.
- Frequency response.

Adding this resistor is a MUST for driving lines, weather you made a linestage or a phono amp made to see only 1 metre of patch cable... better safe than sorry.

Conclusion

Transistors make great slaves for the tubes. A source follower is a very clean device and when put as the top stage in a totem arrangement, you couldn't ask for a more linear representation of what the tube is actually doing.

But as you all are probably shouting at the screen, IT AIN'T A TUBE!

No, it's not. And to my ears, it does sound different.... it sounds like (as in the case of the phono stage above) it isn't even there.

This however should be considered a serious alternative to the traditional SRPP/mu follower/mu stage where the advantages would certainly make it practical.

Cheers!

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(In space, no one can hear your screen)