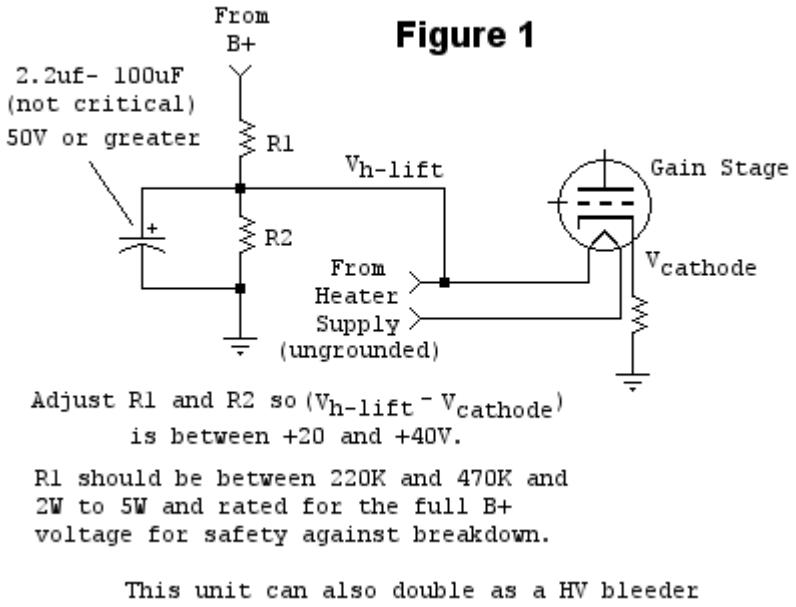
The Underappreciated Hybrid Mu Follower

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 inavertently cause heater cathode breakdown of the bottom tube.



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 particularily 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 particularily 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.

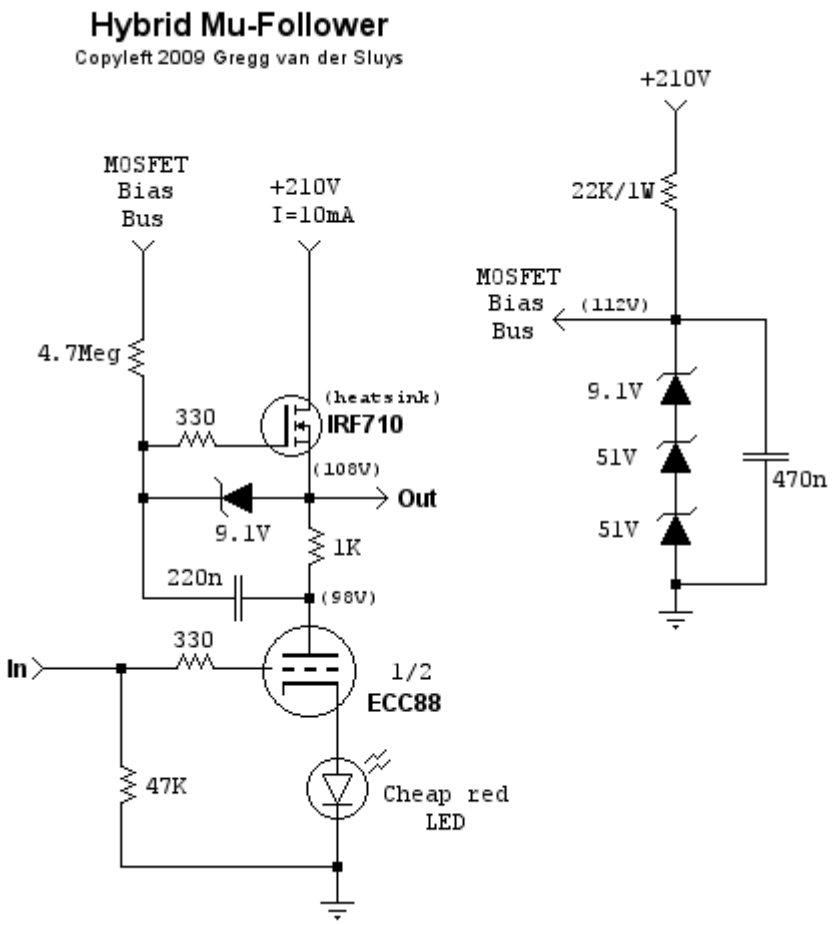
There's one way to cure the problem... get rid of that top tube all together. But how do we do this without sacrificing performance of the topology?

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, particularily 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:



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

In this cicuit, 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+.

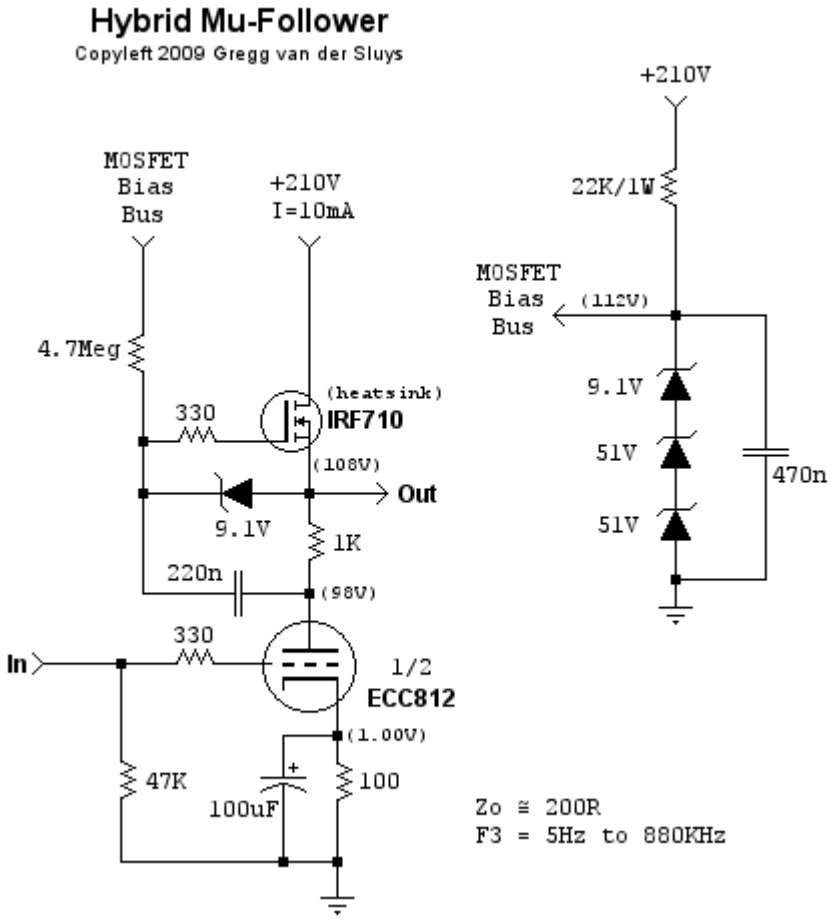
2) The above reason also makes this circuit have really good power supply noise rejection. Therefore, you can use a simpler power supply.

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.

Speaking of frequency response, the LF response on these can suffer as well. Kimmel mentions a gate resistor around 22Meg. I prefer to stick to as small as possible to get the job done and went with 4.7Meg.

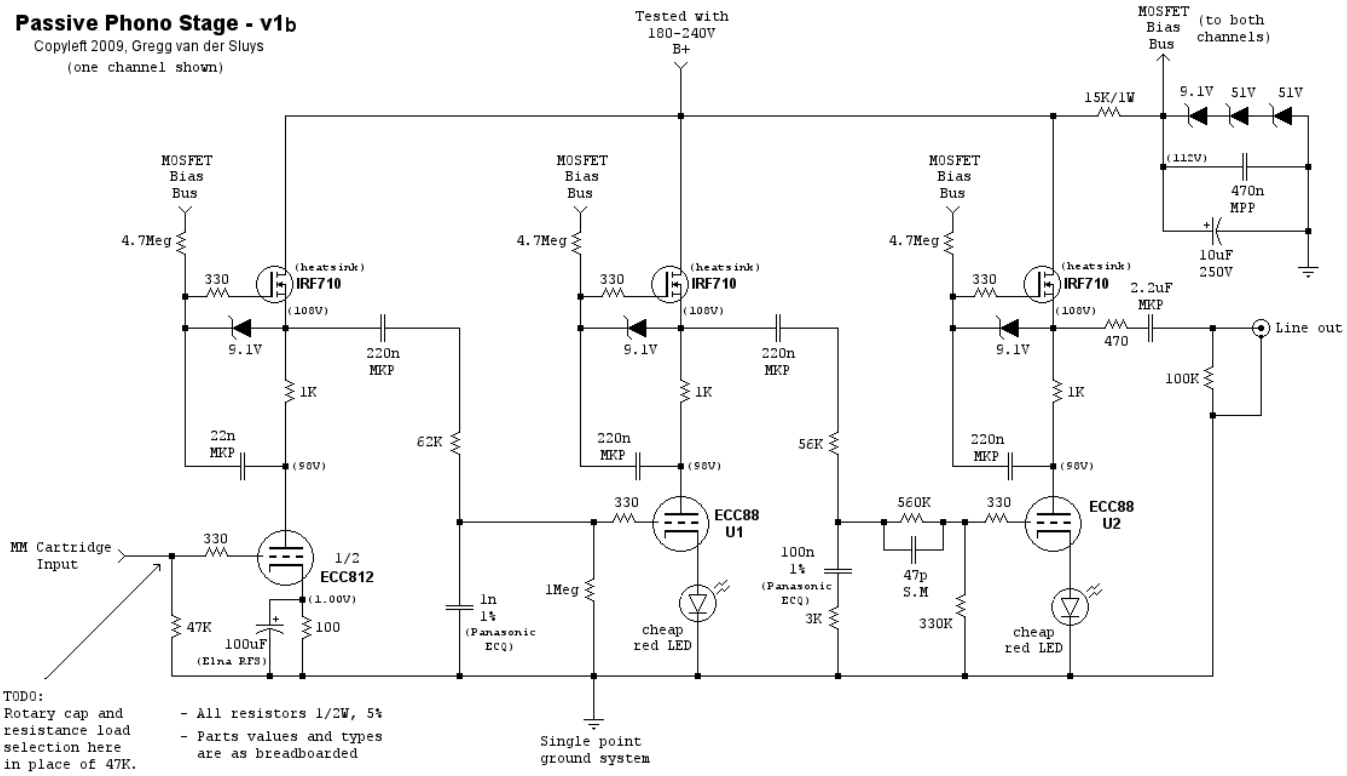
Yes, cou can use smaller capacitors with larger resistors and if what you have are real quality caps in small sizes, go for it. I just happened to have a bunch of super caps of 220nF on hand and got away with a smaller gate resistor.

Now, is this a mu follower or mu stage? Kimmel calls it a mu stage and electrically, the MOSFET acts more like a pentode, especially with the regulated bias supply. But the MOSFET is physically a 3-terminal device and the FFT spectra is more of a triode. You decide.

Practical Circuits

As may have immediately sprang into mind, this hybrid topology lends itself really nice to linestages. Hi-Z input, low-Z output, what's more to love?

But they can also be used for really low level circuits too, as seen in this schematic for my latest MM phono stage (why I played with the ECC812 here):



Notice on the last stage, I have a 470 ohm resistor in series with the DC blocking cap? This is to suppress another tendency of MOSFET's - even in follower mode, put a high capacitance cable on it or long run of anything, you risk creating a VHF tuned line oscillator.

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

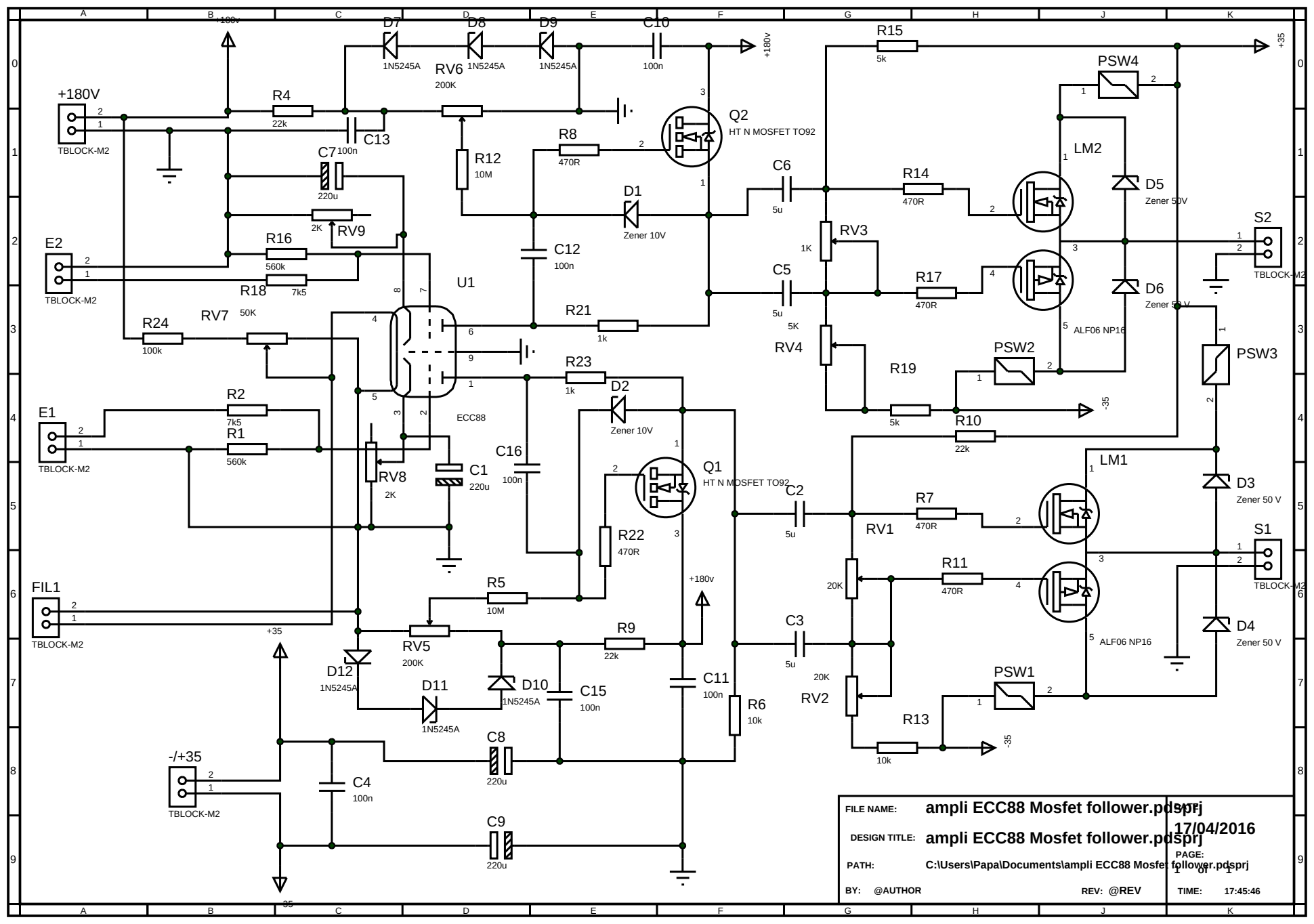
Transistors make great slaves for the tubes. A source follower is a very clean device and when put as the top stage in a totem arrangement, you couldn't ask for a more linear representation of what the tube is actually doing.

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!


+180V
TBLOCK-M2
R4
22k
C13
100n
D7
D8
D9
1N5245A
RV6
200K
C10
100n
+180v
R15
5k
+35
PSW4
Q2
HT N MOSFET TO92
R8
470R
R12
10M
C7
220u
2K
RV9
R16
560k
R18
7k5
E2
C12
100n
D1
Zener 10V
C6
5u
R14
470R
LM2
D5
Zener 50V
S2
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5K
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470R
D6
Zener 50 V
ALF06 NP16
RV4
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PSW2
PSW3
U1
ECC88
R24
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RV7
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