An Input/Driver for a **Hybrid Power Amp**

Here's an interesting circuit for use in a hybrid amp up to 150W.

I have seen many hybrid amplifier designs in recent years. The topologies look similar: with an SRPP (or its brothers/sisters) as the input/driver and power MOSFETs connected in a typical push-pull configuration at the output[1,2]. I have built a few hybrid amps with this basic arrangement over the past five years using the input/driver circuit described in reference 3. I am reasonably happy with the basic design; however, there are at least three limitations that I wish to improve.

1. Voltage gain. Essentially fixed by the valve, but I prefer more flexibility.
2. Output impedance. Usually on the order of around 1Ω (dependent on the output devices), which is a bit high for a solid-state design.
3. Total harmonic distortion (THD). On the order of 2-3% at rated power, which could be much better.

In order not to make the design too complex, I chose to use two triodes (one glass envelope) as in the SRPP version.

This article describes how to design the driver/input stage to improve these conditions. It is aimed more at experimenters than first-timers, devoting more space to design principles than practical implementations.

CHOOSING THE CIRCUIT AND TUBE

The SRPP and variants are popular, but are not necessarily the best choice in a hybrid amplifier. A typical common-cathode and cathode-follower pair may, arguably, be better[4]. Anyway, all these versions cannot improve the issues I mentioned.

A possible arrangement is to use two common-cathode stages in cascade. This configuration was popular 40 years ago in both power and preamp circuits, including the venerable Marantz 7. A two-stage common-cathode amp has too much gain and requires substantial global feedback to reduce it accordingly.

To some users, feedback in audio is sinful. I do not think that feedback is a bad idea provided that the open-loop behavior of the base amp is good. Feedback can make it even better.

I decided to build around a two-stage design based on the common-cathode configuration. With a 70W hybrid power amp in mind, I set some major design criteria (for the input and driver circuit):

- Voltage gain: 26-32dB
- Output resistance: 500Ω or less
- Bandwidth (-1dB): 50kHz or better
- Output voltage swing: 70V peak-peak minimum
- THD: less than 0.5% at rated output

Power MOSFETs have high input resistances; however, their inter-electrolyte capacitances are high, and, consequently, the driver must have low output impedance and a bias current of 10mA or more. Commonly used valves (tubes) such as 12AU7, 6922 are not suitable candidates unless many of them are connected in parallel. I prefer not to parallel active devices, whether for valves or power MOSFETs.

Fortunately, there are many valves on the market that can do the job. A suitable choice is the 5687 and substitutes (more on this later). The output im-

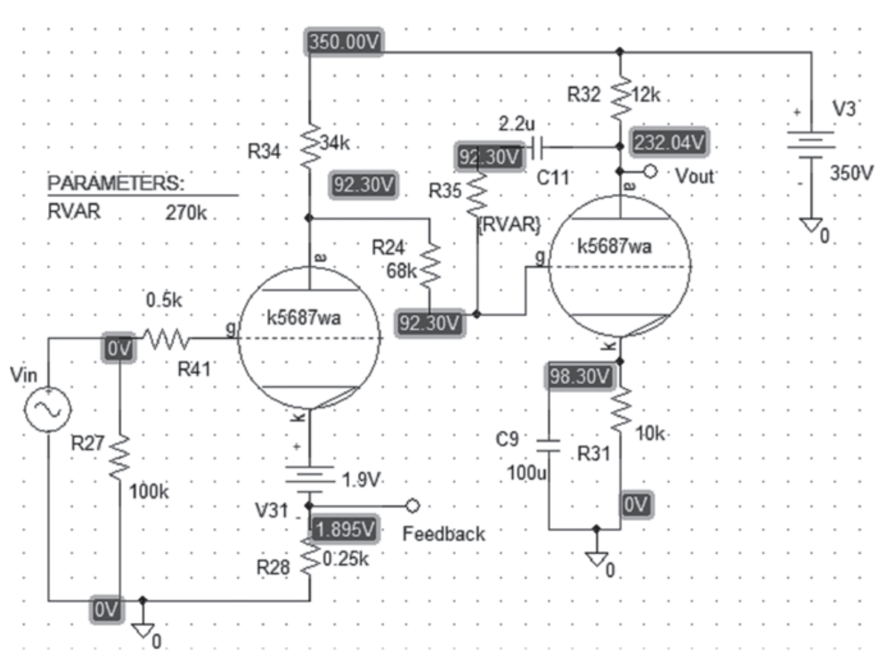

FIGURE 1: The input and driver circuit for a valve/MOSFET hybrid power amplifier.

pedance of a common-cathode stage is mainly determined by the valve's plate resistance r_p and is around 2.5kΩ for a 5687. Therefore, local feedback is required to bring down the output impedance. With the selected circuit and valve, I can now finalize the topology (**Fig. 1**).

STAGE DESIGN

Designing the component values is relatively simple. I first check the typical operation conditions of the valve (5687) and select the following (you can easily download datasheets from reference 5):

- $V_{PK} \approx$ 90V, $I_P \approx$ 7.5mA for the input valve;
- $V_{PK} \approx$ 120V, $I_P \approx$ 10mA for the driver valve.

The first stage, a typical common-cathode amplifier, is directly coupled to the second, and therefore V_P of the first becomes V_G of the second. V_G (of the driver) must be a few volts higher than the corresponding V_G. This helps to determine the supply voltage (around 350V). Simple Ohm's law then determines R31 and R32. The bias voltage of the input valve is around 3.8V. This is achieved by a green LED in series with a suitable resistor (=1.9V/7.5mA≈0.25k). Using Ohm's law again, I can find the value of R34. C9 is used to bypass R31. All relevant component values are shown in **Fig. 1**.

The second stage is a modified common-cathode amplifier. The R35 and R24 combo forms the feedback circuit. Academically, this is a "transimpedance" amp. Some useful design formulas (estimations only) are

- Stage gain (A_{vS}) ≈ R35/R24
- Output impedance ≈ $r_p(A_{vS}/\mu)$, where μ is the valve's amplification factor
- Input impedance ≈ R24 (worst-case)

This type of feedback, though not new, is uncommon in audio circuits. I think the major drawback is that the input impedance loads the preceding stage and hence adversely affects the gain and distortion. To increase R24 seems to be a good solution, but this will compromise the high-frequency response. I consider a suitable range of R24 is from 47k to 82k.

The second step is to fix the stage gain, which determines R35. In the circuit of **Fig. 1**, with R35 equal to 270k, the gains of the first and second stages are estimated to be 10 and 4, respectively. I can vary R35 between 120k to infinity (no feedback) as I wish. C11 should be increased if R35 goes below 120k.

SIMULATION AND MEASUREMENT RESULTS

Basic design equations do not accurately predict the amplifier's performance. A circuit simulator becomes extremely helpful in this department. I use the student version of PSPICE (freely available from www.orcad.com) to evaluate the amp's characteristics.

The DC bias voltages are shown in **Fig. 1**, while the plate current of the input and driver valves are 7.6mA and 9.8mA, respectively. **Figure 2** depicts the frequency response of the amp with

Table 1 Characteristics of the amplifier—from simulation.

R35	Gain (dB)	-1dB Bandwidth	Zout at 100Hz	THD at 1kHz and 35V peak output
120kΩ	24.5	135kHz	335Ω	
270kΩ	30.0	72kHz	493Ω	0.25%
infinity	40.2	20kHz	1.27kΩ	
120kΩ	*24.6*	*133kHz*	*291Ω*	
270kΩ	*31.60*	*67kHz*	*457Ω*	*0.13%*
infinity	*45.2*	*14kHz*	*1.75kΩ*	

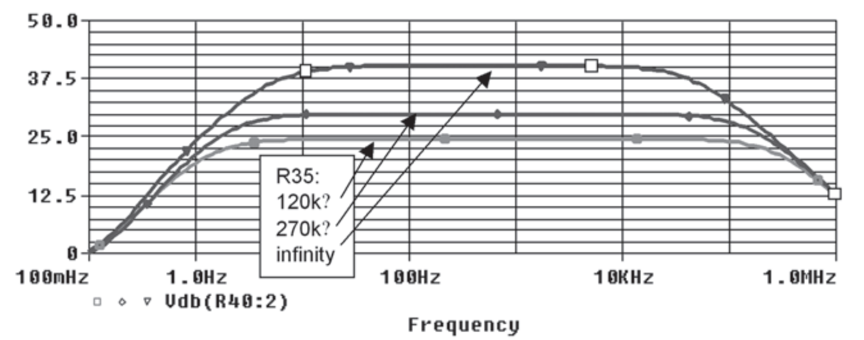

FIGURE 2: Frequency response of the amp. Vertical axis is the gain in dB.

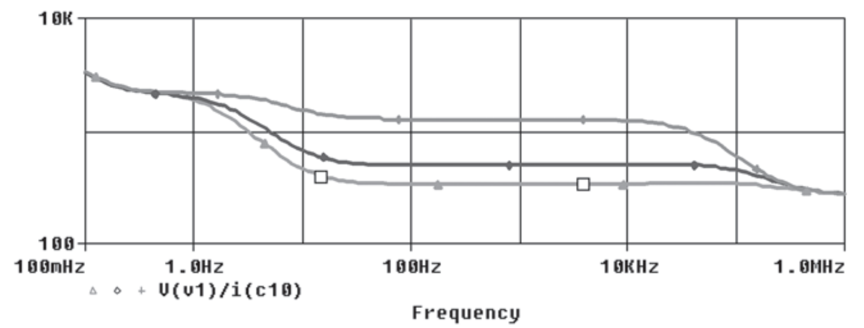

FIGURE 3: Output impedance of the amp. Vertical axis is in ohms.

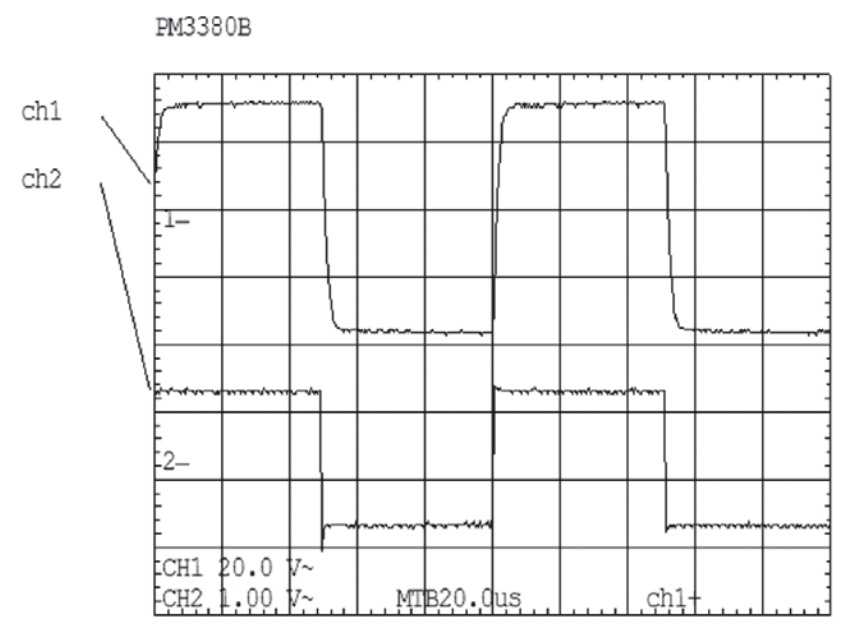

FIGURE 4: Square-wave response of the amp in *Fig. 1*. Ch2 is the input = 1V peak.

three different values of R35. **Figure 3** shows the effect of R35 on the output impedance. **Table 1** shows the details including a high current version (in italics) discussed in a later section.

A real-world test of the circuit revealed the following measurement results (with R35 = 270k):

- Gain: 35 (30.9dB)
- Bandwidth (-1dB): 50kHz
- THD+N (on a HP334A distortion analyzer) at 35V peak o/p: less than 0.24%, 0.1kHz to 10kHz

Figures 4 and **5** contain the square wave and triangular wave responses, respectively, both at 10kHz and around 35V peak. **Figure 6** illustrates that the amplifier is capable of generating a voltage of at least 100V peak-peak without clipping or obvious distortion. Note that noises superimposed on the waveforms are from the digital scope (Fluke PM3380B) itself. No noise can be detected in analog mode.

Some designers/authors do not want users to change the bias conditions or component values. I believe design should be flexible. Provided that some basic design principles are adhered to, you can always modify the circuit as you wish, and that is the fun part.

BIAS CONDITIONS

I have designed a higher current version with R31 and R32 equal to 4.7k and 5.6k, respectively, such that I_P of the driver valve becomes 18mA. Simulation results (**Table 1**) show that this is better in almost all aspects, including gain and distortion. However, I prefer not to tax the lifespan of the valve, although 5687 is capable of dissipating such a power. This is a good alternative if you want to run your valves hot.

You can also change the bias condition of the first valve, but it is better to keep its plate voltage to within 100V. The circuit should perform well with a supply voltage ranging from 310V to 360V. You will need the latter if the circuit is driving a 150W output stage.

VALVES

I use the 5687 tube because I have many of them in my collection. I have used E182CC (7119), which may be considered a direct replacement. Measurements show that the DC conditions are similar, while AC gain is slightly higher and with a better bandwidth:

Gain = 41 (33.2dB) and bandwidth (-1dB) = 55kHz.

ECC99 is another suitable candidate that you can use with an identical design; however, the pin layout is different (so be careful). 6H30 is a very powerful triode that will suit the need well, but the design must be modified.

My design uses the same triode type for the input and driver. Obviously, this is not necessary. You will open up even more choices if you remove this limitation. An essential requirement for the input valve is that it should have a low r_P (so 12AX7 and 6SL7 tubes are out).

LOCAL FEEDBACK VS. GLOBAL FEEDBACK

A push-pull power output stage has unity (or slightly lower) gain with a wide bandwidth and low distortion. Therefore, the input and driver tend to dominate the performance of the amplifier. You can now adjust R35 to your taste. The effect is summarized in **Table 2**. Reducing R35 increases local feedback and reduces gain. On the other hand, this widens the bandwidth, reducing the output impedance and distortion. You can always experiment with R35 ranging from 120k to open-circuit.

I prefer a relatively low output impedance from the driver, but some may suggest that the push-pull output stage is basically a source-follower circuit, and hence the input capacitance is not really an issue for the driver. Note that local feedback is not the same as global feedback; a source-follower uses 100% local feedback, for example.

Unfortunately, I cannot reduce the output impedance of the complete hybrid amplifier by toying around with the input/driver circuit alone. I must use global feedback to achieve this. The use of global feedback has been out of fashion in recent years. In my opinion, global feedback is not necessarily bad, provided that the open-loop behavior of the amp is good. In this case, the circuit is already better than an equivalent current-source driven SRPP[2, 3] and can work perfectly without any global feedback.

For the sake of completeness, **Fig. 7**

Table 2 Effect of feedback on amplifier performance.

R35	Feedback	Gain (Av_S)	Bandwidth	Output impedance	Distortion
↑	↓	↑	↓	↑	↑
↓	↑	↓	↑	↓	↓

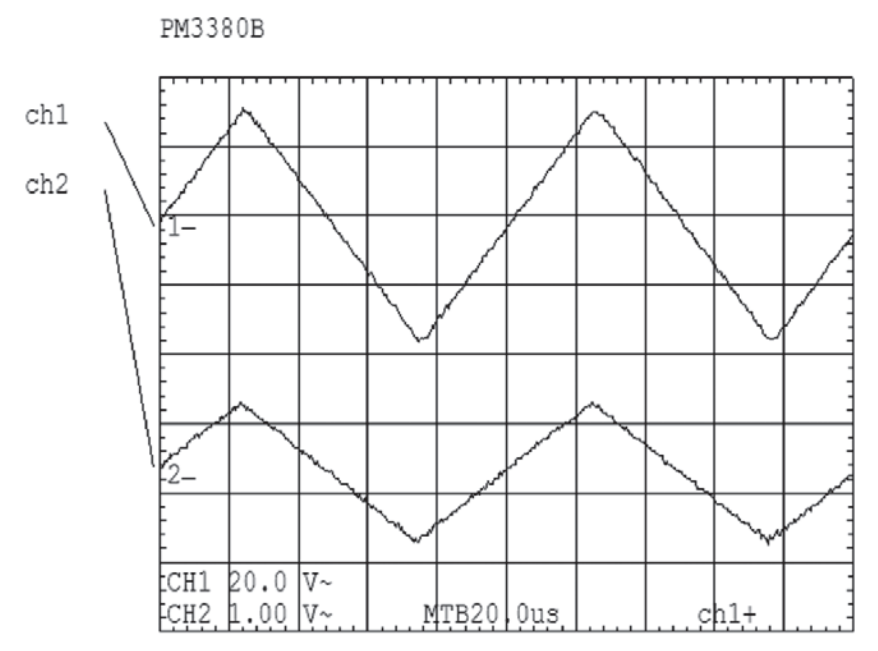

FIGURE 5: Triangular wave response of the amp in *Fig. 1*. Ch2 is the input = 1V peak.

shows the output stage with the associated bias circuit. I use a pair of Exicon MOSFETs ECF10P16/ECF10N16, and the rated output of the complete amplifier is 60W at 8Ω. I apply 7dB of feedback (via Rf with a parallel 100p capacitor—not shown) that reduces the output impedance to below 0.5Ω. The overall gain is 23dB with a (-1dB) bandwidth of over 100kHz. Distortion is even lower than that depicted in **Table 1**. I believe a small amount of feedback is beneficial. Of course, you can experiment to suit your taste. This is a non-inverting amp.

CONCLUSION

I have described the circuit using technical, objective, and measurable terms. . . until now, when I must face the inevitable question: *How does it sound?* I think it measures and sounds better than an equivalent SRPP-driven unit. It is clearer and more open.

After trying E182CC in place of 5687, I was left with the impression that the former is a bit more powerful, maybe even clearer; however, it may occasionally sound marginally harder. 5687 is easier to source and is cheaper, too. I have also tried to use 6DJ8 as the input and ECC99 as the driver, but somehow I am not particularly interested (subjectively) in this arrangement; perhaps you may find a better combination. The circuit is fairly flexible, so readers should feel free to experiment. *aX*

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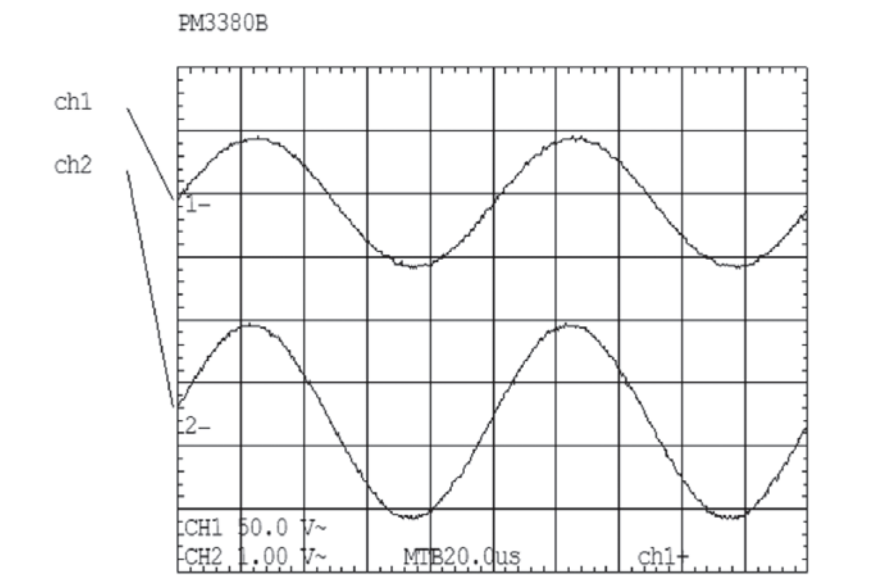

FIGURE 6: Undistorted output voltage at 100V peak-peak.

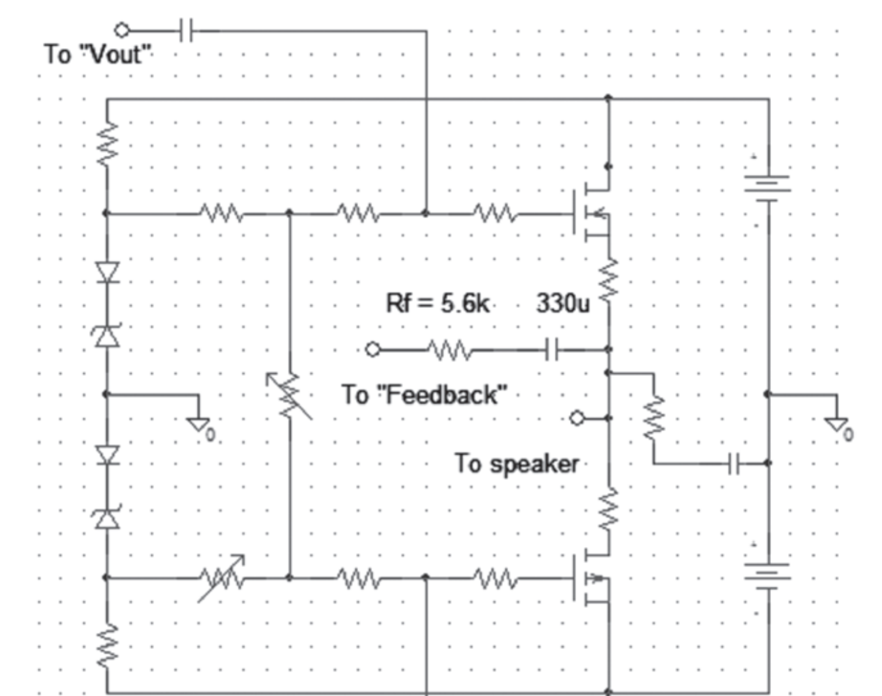

FIGURE 7: The power output stage.