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Design a High-Performance Valve-Based Line Amp

The author describes a new line amplifier design based on the popular SRPP topology.

By Chi C. Wong

This article shows that the performance of this new design is far better than the original SRPP (shunt-regulated push-pull) and its variants. It has better distortion figures and a lower output impedance. You can use the same design as a driving circuit for power valves or MOSFETs.

Instead of providing cookbook-type construction details, I will discuss the design details so that DIYers can design their own circuit using the valve of their choice. The circuit is relatively simple; however, you may need some prior amplifier-building experience. For example, I will not waste space describing power-supply details.

BASIC THEORY

Figure 1 shows a basic SRPP. You may consider that the plate of the lower valve (V_1) sees a high impedance load formed by the upper valve (V_2) and R_2. For a good approximation, the plate impedance seen by V_1 is around $\mu \times R_2$ (μ is the amplification factor of the valve). So if R_2 is large, then the gain is high (close to μ) and distortion is low. Also, if R_{12} is high enough, then V_2 is working like an ideal cathode follower with a low output impedance. In practice, this does not happen because R_2 cannot be too high—typically 1k—as the voltage drop across it determines the DC bias voltage for V_2.

Figure 2 shows an improved circuit called the mu-follower. In this design, the voltage across R_2 still provides the required bias for V_2 as in **Fig. 1**, but both valves are now seeing load impedances of around $\mu \times (R_2 + R_3)$ at midband. This arrangement improves the performance of the original SRPP with better distortion figures and lower output impedance. However, a large R_3 requires a much higher VBB. Due to practical reasons you normally must limit R_3 to a few kΩ.

Figure 3 shows the new design I am currently proposing. In this case, I re-

FIGURES 1-2-3. FIGURE 1 (left): Basic SRPP. FIGURE 2 (middle): Mu-follower. FIGURE 3 (right): New design.

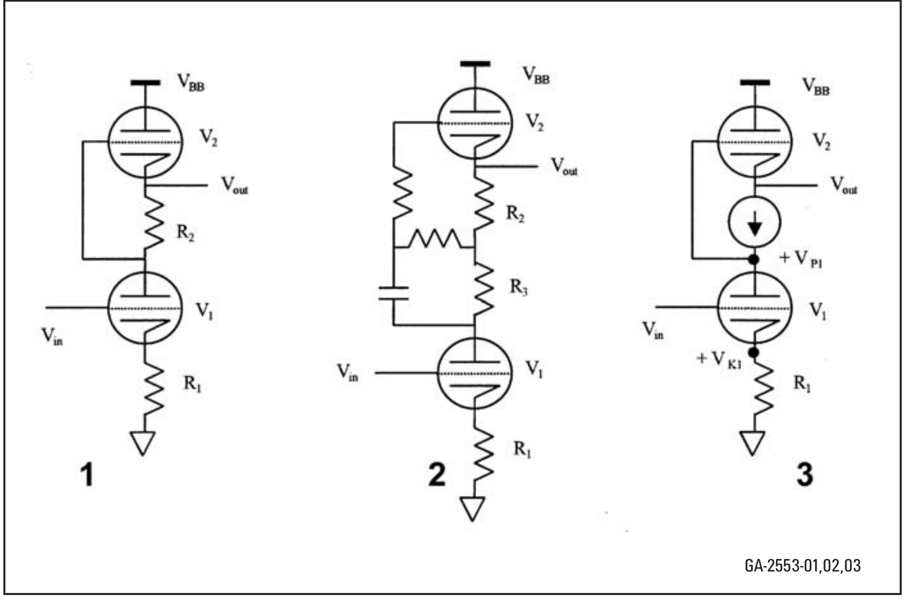
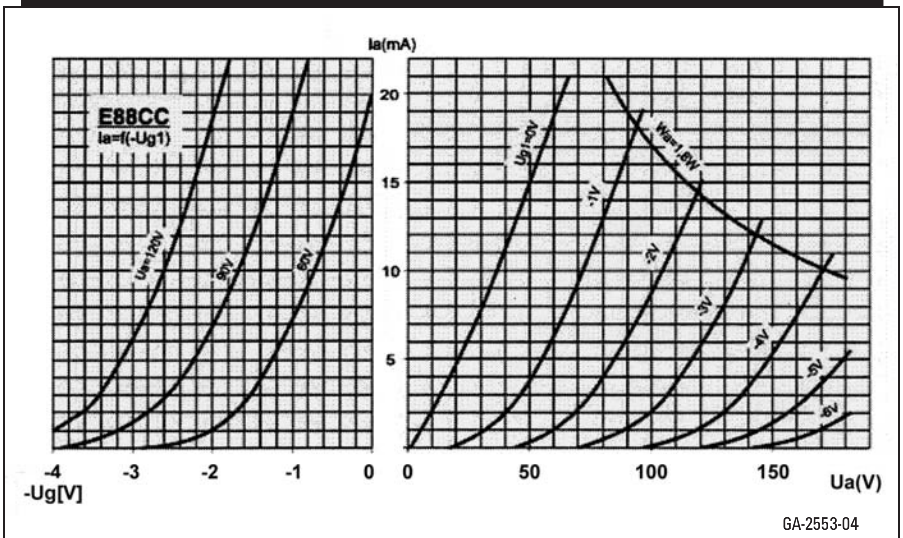


FIGURE 4: Characteristics of 6DJ8.



place R_2 with a suitable current source, which (in theory) has an infinite impedance. The current source provides the required bias current for both V_1 and V_2 while the voltage across this current source automatically generates the bias voltage for V_2. This circuit topology provides ideal working conditions for both valves.

DESIGN AND IMPLEMENTATION

In the circuit of **Fig. 3** the top and lower valves are connected by a current source, which stabilizes the bias current. Due to its high output impedance, both the top and lower valves are seeing resistors of extremely high values (at least 100s of kΩ). Consequently, the linearity, gain, and output impedances are close to the theoretical best without the use of feedback.

The design process has two major steps. For convenience, I select the popular 6DJ8 (6922, E88CC equivalent) to show the process.

The first step is to establish the bias conditions. **Figure 4**[1] shows the transfer and plate characteristics. You first select a suitable operation point for the lower valve. I select the following conditions:

I_P = 6mA
V_{PK} = 90V
V_{GK} = –2V

The value of R1 is then found by Ohm's law:

R_1 = 2V/6mA = 0.333kΩ

In principle, I can apply the same condition to the upper valve; however, it is better to run this valve with a deeper bias and a higher voltage. The reason will be obvious later. So I use the following:

I_P = 6mA
V_{PK} = 120V
V_{GK} = –3V

From these conditions I can calculate the required supply voltage:

V_{BB} = (2+90+120+3) V = 215V.

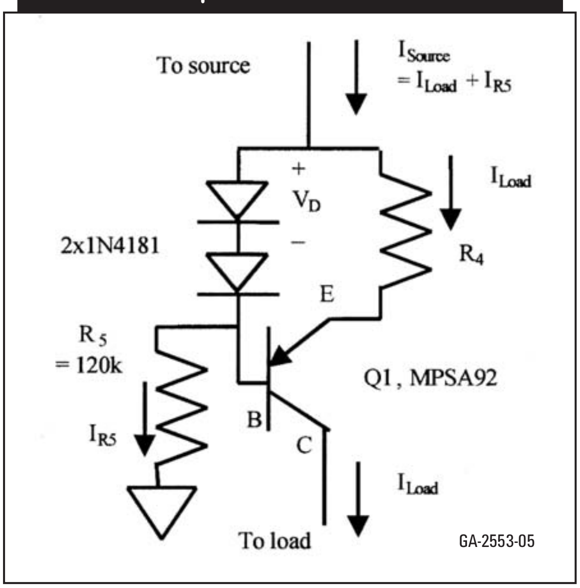
The second step is to build the current source. I have started with a three-terminal variable current source; however, I have a noise problem. Constant-current diodes appear to be suitable, but I don't have them in my toolbox. So I returned to using a transistor-based current source, which is shown in **Fig. 5**.

Using the basic design equation, R_4 is calculated to be 108Ω for a bias current of 6mA. A suitable value for R_5 is around 120kΩ. See sidebar for details. In this case the bias current I_P is I_{Load}.

Figure 6 shows a complete line amp based on this new topology. I have replaced R_1 by three series-connected diodes (1N4181), which provide the 2V bias. This change greatly extends the bandwidth. R_4 becomes 100Ω because it is more readily available. The bias current is slightly higher. However, I do not think that the bias current must be exactly 6mA. Indeed you can always select your own favorite operation point. The voltage across the current source is around 3V, which is also the bias voltage for V_2.

In this design the signal voltage is not expected to exceed 2V peak; otherwise, the current-source may not function properly, or a deeper bias should be selected. Because the circuit is drawing a constant current (around 7mA in this case), a typical supply with CRC filtering will do the job well. I have no intention of describing constructional details here; however, a few hints will be helpful.

FIGURE 5: A simple current source.



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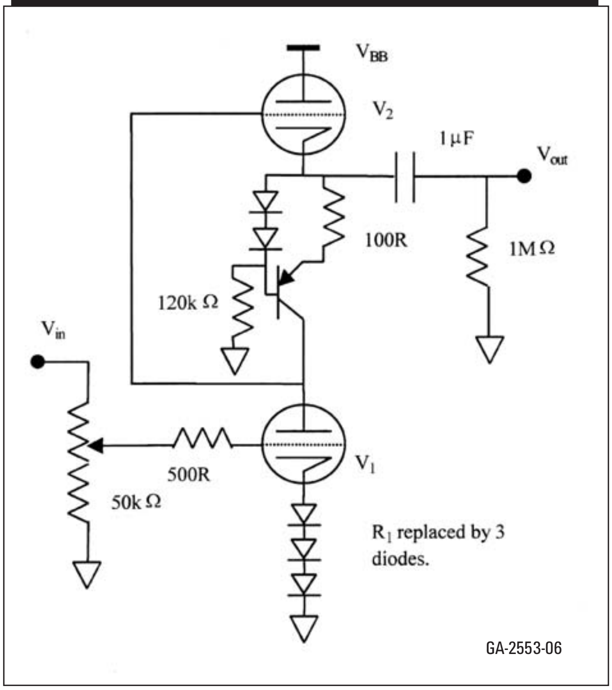
- I use a chassis-mounted valve socket with a tagboard to implement the design. You may prefer to build a pcb.
- If you prefer to precisely adjust the bias current to your designed value, I suggest you use paralleled resistors for R_4 instead of a pot.
- The current source will pump current as soon as it is on, so you should turn on the heater filament supply at least 15s before the high voltage (V_{BB}).
- I do not recommend that you use this circuit with 12AX7 (or the like), which needs a bias voltage of around 1V.

FIGURE 6: Practical implementation of the current proposal using 6DJ8.



TEST RESULTS

Table 1 shows the measured bias conditions of the current design using a Gold Dragon 6DJ8. **Tables 2** and **3** show the measured performance and distortion figures, respectively. I tested the circuit with a relatively large output voltage swing because I am also using a similar circuit as a driver for a hybrid amplifier. (6DJ8 is not a good choice in this case.) If you use the design as a line amplifier, the THD will be substantially lower. Also, the THD remains at

TABLE 1: Bias conditions (refer to Fig. 3).

V_{K1}	I_P	V_{BB}	V_{P1}
2V	7mA	215V	84V

TABLE 2: Basic performance.

-1dB bandwidth	Gain	Output Z
3.7MHz	28	115Ω

TABLE 3: THD+N (from HP334A distortion analyzer) with output voltage kept at 40V peak-to-peak.

Load	100Hz	1kHz	10kHz	30kHz
100kΩ	0.95%	1.0%	0.9%	0.86%
10kΩ	0.82%	0.82%	0.85%	0.83%
100kΩ	2.2% at 100Vpp			

a respectful value even at an output of 100V peak-to-peak.

VARIATIONS

In the design of **Fig. 6**, I have defined the bias voltage using the diode voltage drops and the bias current by the current source. I can simply replace the 6DJ8 with 12AU7 without modifications (except that the heater voltage requirement is different). As a line amplifier, the 6DJ8 sounds and measures better. You can turn the circuit back into the basic SRPP by replacing the current source with a suitable resistor.

In the 6DJ8 example, this resistor is 3V/7mA = 430R. I have tried other valves such as 12AU7, 6H30, ECC99, and 5687, and in all cases the performance of each is substantially better than the SRPP equivalent. It is a simple matter to test for yourself, but do not forget to redesign the bias conditions for your favorite valves. *aX*

REFERENCE

1. Taken from **www.rarefaction.com.au/datasheets/jjecc88.html**.

CURRENT SOURCE DESIGN

If you assume:

1. $V_D = V_{EB} = 0.65V$ when "on"

and

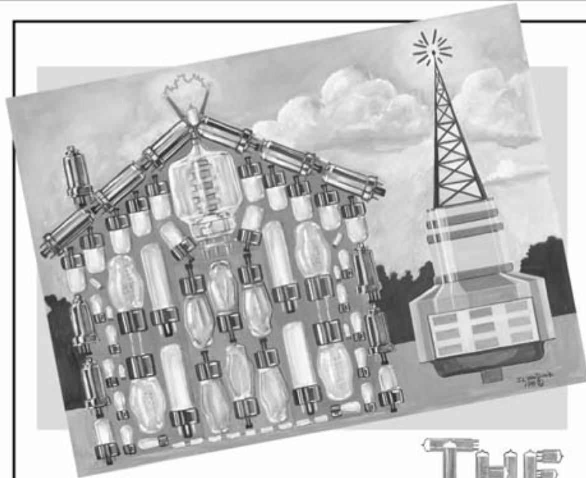
2. $I_C = I_E$

then $I_{Load} (I_C = I_E) = 0.65/R_4$

Or $R_4 = 0.65/ I_{Load}$

Note that:

1. The accuracy of this equation is not high because the 0.65V drop is an approximation.
2. I_{Source} is around 0.5mA to 1mA higher than I_{Load}. The difference depends on I_{R5}.
3. The voltage drop across the entire current source must be larger than 1V to ensure that Q1 does not run into saturation.



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