Getting LESS Gain From Tubes

By Merlin Blencowe. First published in AudioXpress, May 2025, pp28-9.

This article was prompted by a comment that came up on an internet forum:
"*It seems to be somewhat difficult to get very small amounts of voltage gain in tube circuit*s."
I can understand why the commentor would get that impression. There is no shortage of textbooks and websites that explain how an ordinary common-cathode gain stage works, or a cascode, or even an SRPP or mu-follower, but all these stages tend to deliver significant gain. Even if we choose a particularly low-µ tube like the 12AU7 we will probably end up with a gain of at least ×10 (20dB). Then the textbook turns to the familiar cathode follower, with its gain close to unity. What happened to the gap in between? There are plenty of applications where we might want just a little gain, 2 to 3 for a line stage, say. One solution is a stage with local shunt feedback (analogous to an inverting opamp stage), whose gain can be tweaked to whatever we like. But such a circuit has the disadvantage of low input impedance, or else we use such large resistances that it becomes extremely noisy. The textbooks do not always make it obvious that *series* feedback can alternatively be used to obtain whatever gain we like –albeit with different tradeoffs. I therefore thought it might be useful to explain the process here, in simple terms.

As we ought to know by now, the gain of an ordinary common-cathode stage, when the cathode is bypassed, is:

$$A = -\mu \times \frac{R_a}{R_a + r_a} \tag{1.1}$$

We will ignore the minus sign from here since it only indicates that the stage is inverting, and needlessly confuses the algebra. Now, if we leave the cathode bias resistor unbypassed as in fig. 1 then, as everyone knows, the stage will be degenerated and the gain will be somewhat reduced:

$$A_{\text{degenerated}} = \mu \times \frac{R_a}{R_a + r_a + (\mu + 1) R_k} \tag{1.2}$$

By itself this is likely to reduce the gain by a relatively small amount, but we can leverage this effect to reduce gain further. Let us take the original load resistor R_a and split it into two parts, R_1 and R_2, as illustrated in fig. 1. In other words, let us steal some resistance from the plate circuit and shove it into the cathode circuit instead. The total degenerating resistance is now formed by the combination of R_k + R_2:

$$A_{\text{degenerated}} = \mu \times \frac{R_1}{R_1 + r_a + (\mu + 1)(R_k + R_2)} \tag{1.3}$$

If we break R_a into two equal parts, for example, so half the total load is in the anode and half in the cathode, then the gain will be just under unity and the circuit looks suspiciously like a cathodyne or split-load phase inverter. Intuitively then, we must be able to tweak the gain anywhere from 'normal' or maximum, down to 1 (indeed, we could go further still, but for gain less than 1 we might as well use an attenuator). Since the total resistance in series with the tube has not changed, the voltage *across*

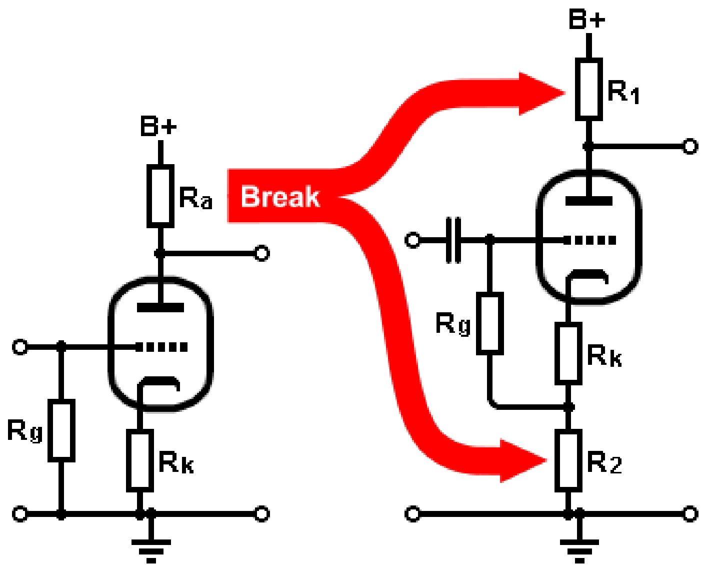

Fig. 1: Gain can be reduced to any degree by taking some of the anode load and placing it in the cathode.

the tube, and the current through it (i.e. bias) are also unchanged. Whatever value we would have used for R_a as a 'normal' gain stage still applies, it is simply broken into two parts now.

If we have a target gain in mind, A, then we can re-write the equation above to find exactly what fraction, K, of the original load resistance to leave in the anode while the remainder will go to the cathode:

$$K = \frac{A}{A+1} \times \frac{r_a + (\mu + 1)(R_a + R_k)}{\mu R_a} \tag{1.4}$$

For example, suppose we had an existing gain stage using a 12AX7 where μ=100, r_a = 70kΩ, R_k = 1.8kΩ, and the original load resistor is R_a = 100kΩ. It has far too much gain for our needs, and we would like to reduce it to A = 3:

$$K = \frac{3}{3+1} \times \frac{70k\Omega + (100 + 1)\times(100k\Omega + 1.8k\Omega)}{100 \times 100k\Omega} = 0.77$$

In other words, we must keep 77% of the original load in the anode, and put 23% in the cathode, so R_1 = 77kΩ and R_2 = 23kΩ.

There are some other points to note. By shoving resistance into the cathode circuit, the idle grid voltage is raised, so a DC blocking capacitor becomes necessary at the input, but in most circuits there is a coupling capacitor here already, in which case nothing more is required. Since we are creating a stage with local *series* feedback, other performance changes are basically the opposite of what we would get for a stage with local *shunt* feedback. The input impedance increases, which is usually welcome. It is rather laborious to calculate exactly, but it will increase roughly in proportion to the gain reduction. The output impedance also increases at first, which is less welcome, but the change is not necessarily large, depending on the tube used. PSRR will be made worse, but it is seldom very good for a triode gain stage to start with, so this is a minimal concern. Distortion will be reduced approximately in proportion to the amount of gain reduction. This is a welcome result of course, though the maximum available output swing will also shrink as we reduce the anode resistor.

Test	R_1	R_2	Gain	THD @ 10V	Computer simulated Z_{in}	Computer simulated Z_{out}
1	100 kΩ	0 Ω	28.5	0.49%	1.0 MΩ	72 kΩ
2	96 kΩ	3.6 kΩ	13.3	0.23%	2.03 MΩ	83 kΩ
3	91 kΩ	10 kΩ	6.55	0.14%	3.85 MΩ	85 kΩ
4	77 kΩ	22 kΩ	2.94	0.08%	7.29 MΩ	75 kΩ

Table 1: Summary of test data for the ECC83; refer to fig. 2.

As a practical example, the circuit in fig. 2 was tested using a JJ ECC83S with a supply voltage of 300V. Table 1 summarises the results, where R_1 and R_2 were chosen to approximately halve the gain each time. The final case uses (very nearly) the values calculated earlier, and produced a gain of 2.94. It is easy to see the reduction in distortion, as well as the reduction in output headroom.

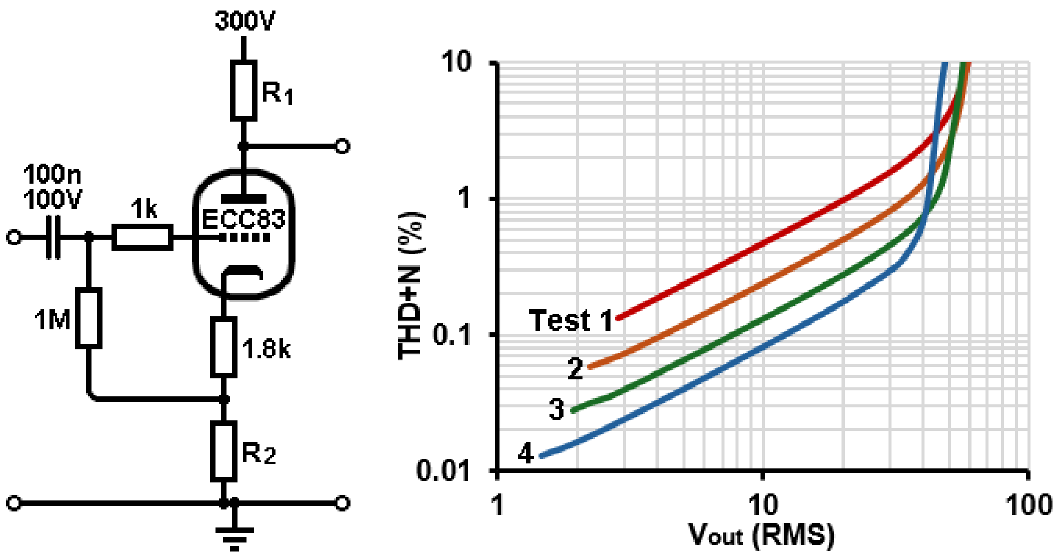

Fig. 2: ECC83 test circuit and measured total harmonic distortion at 1kHz; refer to Table 1.

At the editor's request I repeated a similar set of tests for the circuit in fig. 3, using a Mullard ECC88 (6DJ8) with a supply voltage of 200V. Results are given in Table 2, and the same trend is clear. The lower voltages and impedances in this setup also made it possible to connect a noise meter directly to the output, and the readings are also listed in Table 2 (20-20kHz unweighted, input shorted to ground). Noise on the power supply itself was about 10µV. These figures are presented for interest only; noise is not a design concern since a very-low-gain circuit would never be needed in an application where the audio signal is very small. Perhaps this article will prove useful to anyone seeking small, precise amounts of gain from tubes.

Test	R_1	R_2	Gain	THD @ 10V	$Noise_{out}$	Computer simulated Z_{in}	Computer simulated Z_{out}
1	22 kΩ	0 Ω	12.5	0.58%	30µV	1.0 MΩ	12.7 kΩ
2	21 kΩ	1 kΩ	7.61	0.39%	17µV	1.59 MΩ	15.7 kΩ
3	19 kΩ	3 kΩ	3.97	0.23%	13µV	2.77 MΩ	16.5 kΩ
4	16 kΩ	5.6 kΩ	2.18	0.19%	11µV (hum)	4.33 MΩ	14.9 kΩ

Table 2: Summary of test data for the ECC88; refer to fig. 3.

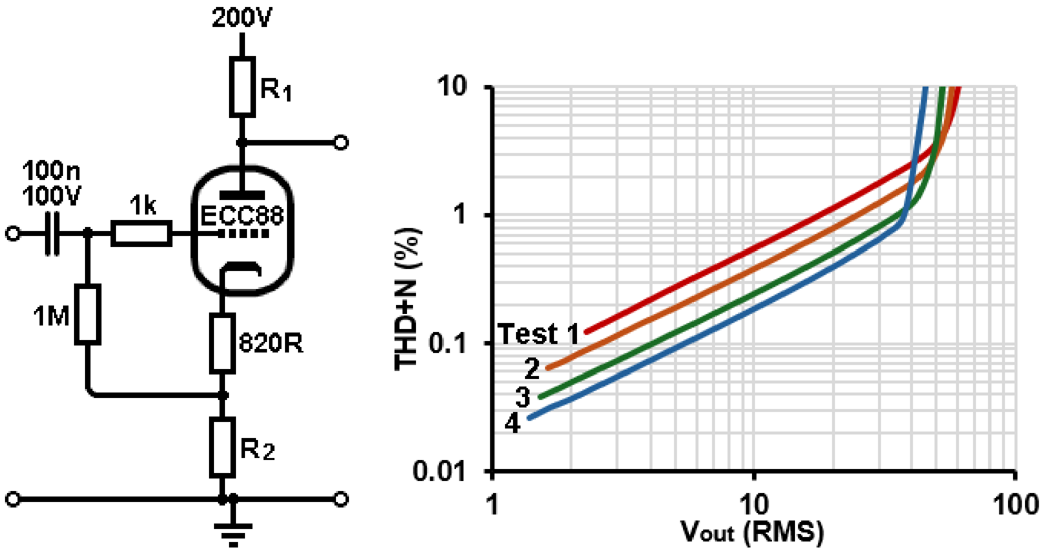

Fig. 3: ECC88 test circuit and measured total harmonic distortion at 1kHz; refer to Table 2.