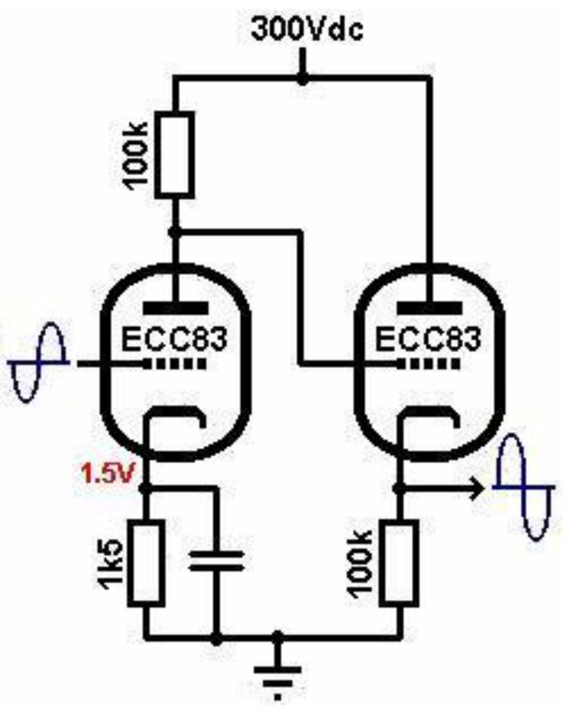
The Valve Wizard

How to design valve guitar amplifiers!

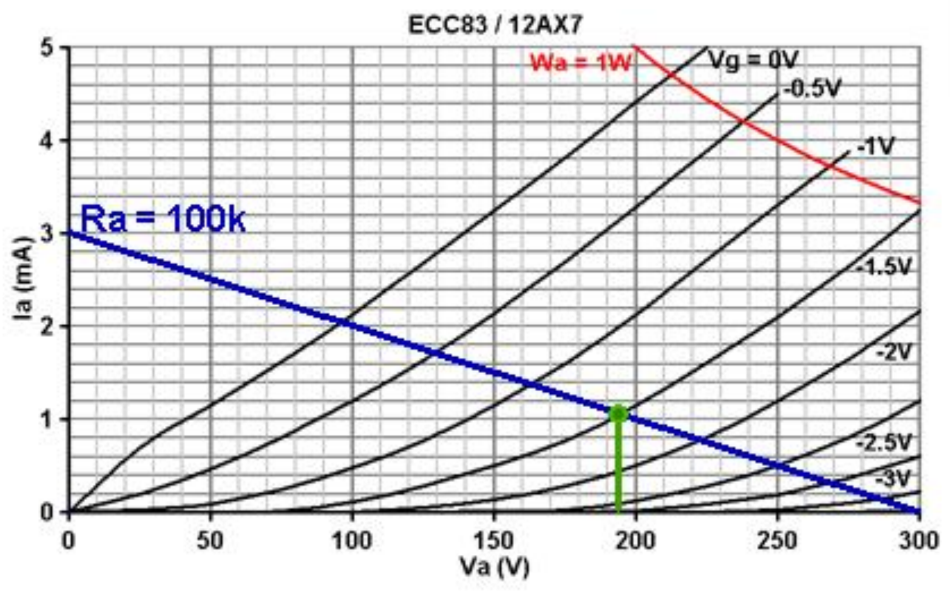
The DC Coupled Cathode Follower



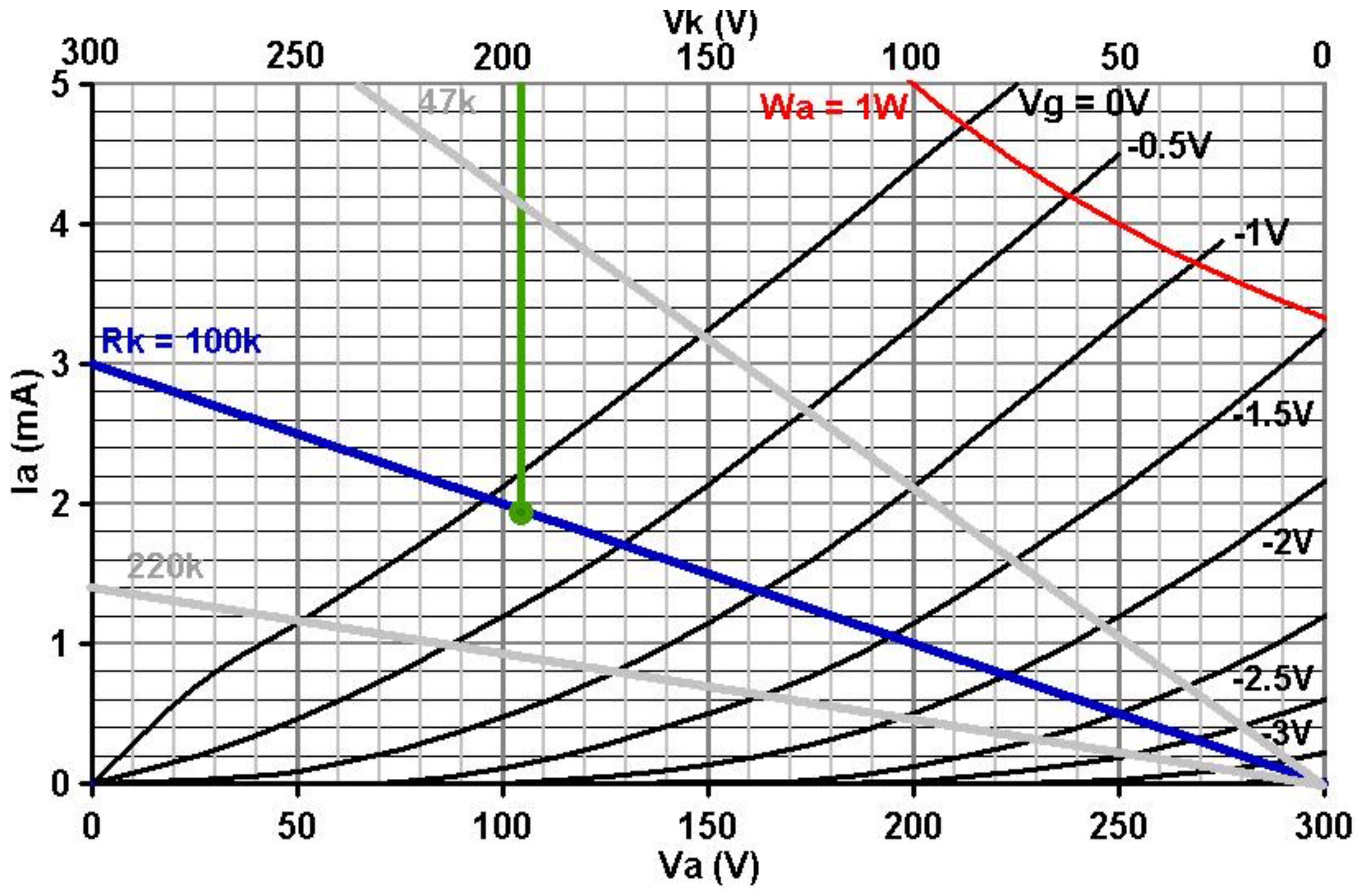
From a technical point of view, the cathode follower found in many guitar amps appears quite ordinary. It usually drives a tone stack, which would otherwise present quite a heavy load to a 'normal' gain stage and would result in considerable signal attenuation. The low output impedance of a cathode follower, however, can drive current into heavy loads more easily.
However, the cathode follower found in guitar amps is quite peculiar. As well as simply driving a tone stack, it has more effect on overall distortion than any other stage in the preamp. A glance at any very high gain amp will usually reveal at least one of these stages, and sometimes several, at various points i n the preamp. What's more, the stage works so well and sounds so good because it is fundamentally "badly designed", at least, from the 'textbook' point of view.

The circuit universally consists of an ECC83 gain stage, DC coupled to an ECC83 cathode follower (usually in the same envelope), each with 100k load resistors. The biasing of the gain stage is not particularly important, and follows normal conventions. So what makes this circuit so interesting? Examination of the load lines should make this clear, and reveal why such a badly designed stage works so well. This example will use a 300V HT, although the actual voltage is not critical for obtaining good results.

The load line to the right is for the gain stage. The bias point could be set almost anywhere along it, although somewhere in the middle is usual, in this case -1.5V (green dot), making the quiescent anode voltage about 195V. This is the first reason why the circuit is badly designed; the anode voltage of the gain stage is quite high. A text book example would bring this down to about ½ HT or lower, by using a larger load resistance or smaller bias voltage.



The load line below is for the cathode follower. Remember, the x-axis shows anode-to-cathode voltage, but we are also interested in the cathode-to-ground voltage. This can be easily added by reversing the anode voltage scale, since when no anode current flows, the cathode voltage would be zero. This scale has been added to the top of the graph.



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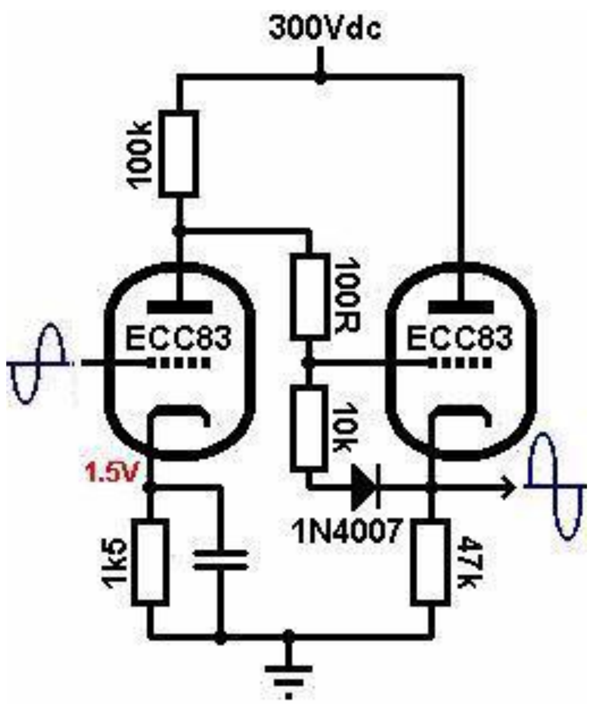
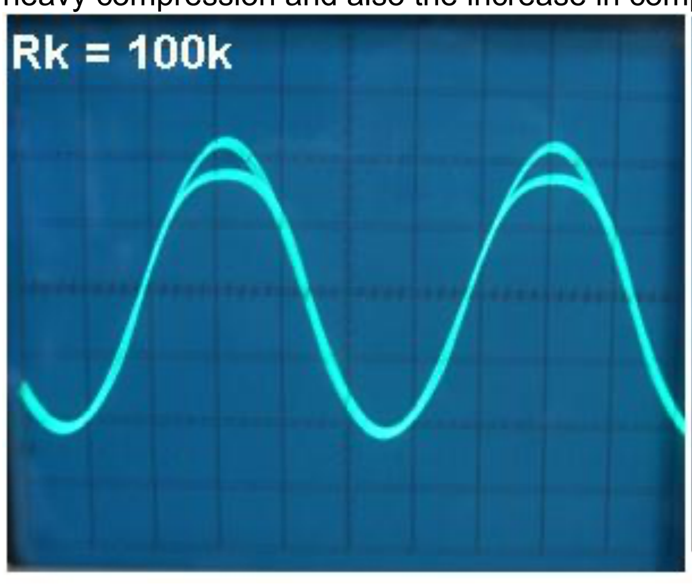
We know that for normal operation the cathode will be a couple of volts higher than the grid (which is connected to the anode of the previous stage and is therefore at 195V), but for simplicity we will assume it is at the same voltage as the grid, or 195V- it will not affect our analysis. Looking at the load line, for a cathode voltage of 195V the bias point appears to be very nearly on the 0V grid curve. In reality we know that the cathode should be a couple of volts more positive than this, but that simply pushes the bias point even further up the load line! The problem is, by having a high anode voltage on the previous stage, we are forcing the cathode follower to bias so hot that it will be beginning to draw grid current. This will drag down the anode voltage of the previous stage and simultaneously raise the cathode voltage of the follower, increasing its bias. Eventually an equilibrium point will be reached where the grid current generates enough bias to prevent any further increase in grid current. In other words, the valves will come to rest with grid current *permanently* flowing into the cathode follower (experimentation suggests about 0.4mA or so). All this happens very quickly at switch-on of course.

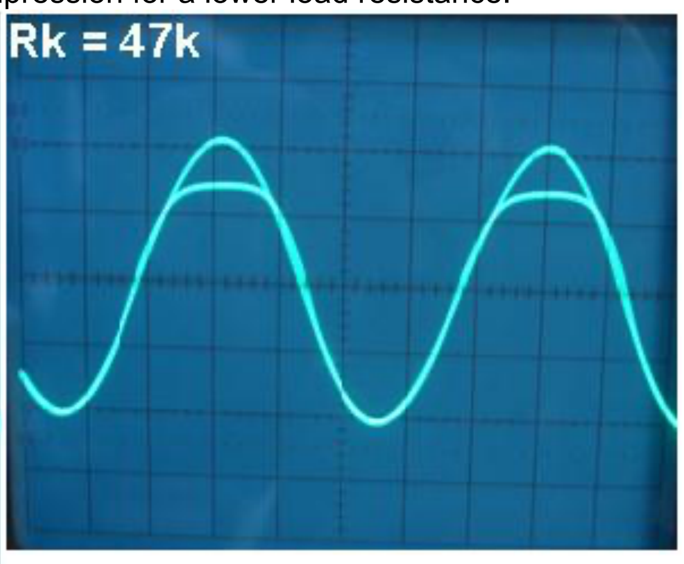
This is the second reason why the stage is badly designed; we 'should' have used a triode with a much lower anode resistance, such as an ECC82, which would make the grid curves steeper and would allow "normal" biasing. Another option would have been to increase the follower's cathode load resistor, to say 220k (shown in feint on the graph) which would also allow a more normal bias point of about -0.75V, although the large resistance would retard the "textbook" performance of the follower.



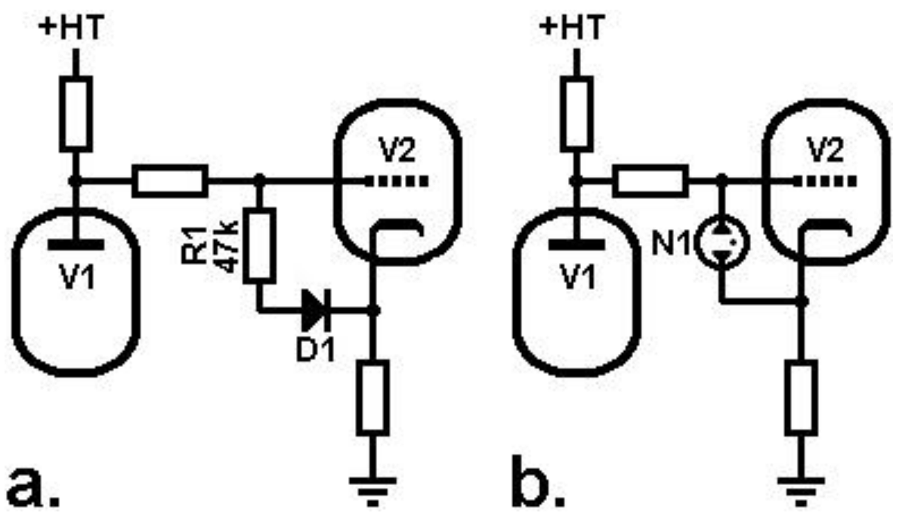
So we now have a cathode follower that is permanently 'stealing' current from the previous stage; what is the result? If a down-going signal appears at the gain stage's anode the grid voltage of the follower is pushed down back into the area of "normal operation", and grid current stops flowing more or less immediately, for the duration of that cycle. But when the incoming signal is positive going the grid is pushed more positive, which induces even more grid current to flow into the cathode follower as it tries to maintain bias, which in turn 'drags down' the anode voltage of the gain stage which is trying to move positive! In other words, the up-going cycles are very heavily compressed, but the down going ones are not, which generates a lot of second harmonic distortion. This is only made possible by the DC coupling, and is why this circuit is so often used in high gain amps- it can warm up a signal that already contains too many high-order harmonics, and return a rather fuzzy sound to a rich, creamy distortion tone. The effect can be increased by lowering the follower's cathode load resistor, to say, 68k, 56k or even 47k. A 47k load line is also shown in feint on the graph above, and clearly shows that the bias point wants to be well above the 0V grid curve- so considerable grid current must flow to force the voltages to allow the follower to bias sufficiently, and experimentation suggests this is around 0.8mA. This causes even more compression, and is perhaps the easiest way to warm up the tone of an amp- the difference is immediately obvious, and far better value-for-money than fiddling around with coupling capacitor types or carbon comp' resistors. The circuit on the right is my preferred version (the added resistors and diode are protections components and do not affect tonality, see below.)

The oscilloscope traces below show a ~20V p-p, 1kHz output from the cathode follower and the input signal to the gain stage's grid (which has been inverted and scaled for comparison). Notice how only the positive part of the cycle is affected, clearly demonstrating the heavy compression and also the increase in compression for a lower load resistance.





A Useful Mod' for DC-coupled cthode followers:
It is very common to see a DC coupled cathode follower in a guitar amp, often before a tone stack. The traditional arrangement suffers from the problem that on start up, the grid will immediately rise to HT potential while the cathode is still cold, at ground potential. It is not unknown for this to cause arcing between the electrodes, and rapid destruction of the valve, even when a standby switch is used (I have burnt out more than one valvwe this way!). This problem can be easily corrected by connecting an ordinary rectifier diode (such as a 1N4007) and resistor between grid and cathode [diagram **a**]. At start up, this will keep the cathode within a few tens of volts of the grid. Once hot, the valve will bias with the cathode at a higher potential than the grid and the diode will be reverse biased, off. The resistor is included to prevent any switching noise that might be caused if the cathode follower were overdriven (in a hifi circuit the resistor would be omitted).



When reversed biased a diode acts more-or-less like a capacitor. The capacitance of most diodes is of the order of 10pF. This is not a worry though, because capacitances between the grid and cathode are *divided* by open-loop gain of the follower, so will reduce this to an effective value of less than 1pF typically.
Another solution [diagram **b**] is to use an ordinary neon bulb (not the kind advertised as mains indicators as these have a resistor built in). The neon will strike if the grid-cathode voltage exceeds about 90V, which is probably ok for most valves, but maybe not for high-gm types like the ECC88 which have a very close grid-cathode spacing.

Bootstrapping for more gain:
Because the cathode follower acts as an impedance buffer we can use it to 'bootstrap' the previous stage. This is done by splitting the previous stage's anode resistor into two equal parts and connecting a capacitor from the cathode follower's cathode, to the junction of the two resistors [see right]. The cathode follower then effectively multiplies or bootstraps the value of the lower anode resistor R2, making it look like a constant-current source. This will increase the gain of the previous stage so it becomes almost equal to the mu of the valve! An added bonus is that if you don't use a cathode-bypass capacitor, the gain is still very hgh (about 85-90 with an ECC83). Leaving the cathode unbypassed reduces blocking distortion and reduces 'fizzy' sounding overdrive, giving better crunch. Usually you sacrifice a lot of gain though, but not in this case! So I guess you *can* have you cake and eat it too...