### 10.1.1 Preamplifier tube

**Fig. 10.1.1** juxtaposes the circuit of a triode as it is typically used in input stages of guitar amplifiers, and an N-channel-JFET circuit. These circuits are not equivalent but the comparison will assist the solid-state-expert to easily access to the world of tubes. The three electrodes of the **triode** are designated **cathode**, **grid**, and anode or, more commonly used, **plate**. They correspond to source, gate, and drain in the JFET. Unlike with the FET, the tube requires a heater current (about 0,3 A at 6,3 V) that normally is not shown in the schematic. Tubes operate using very high supply-voltages ($U_B$ = 200 – 400V) i.e. 10 times the value for the FET. On the other hand, the currents flowing in the plate- and in the drain-circuit are comparable: for input stages, they amount to about 1 – 2 mA. The voltage between grid and cathode (gate and source) constitutes the control quantity; for small drive levels, the input (grid, gate) is of very high impedance – i.e. the grid-(gate)-current through the grid-resistor (gate-resistor) $R_g$, is negligible. The cathode-(source)-current therefore is equal to the plate-(drain)-current. For a cathode-(source)-current of 0,8 mA we find a voltage of 1,2 V across the cathode-resistor $R_k$ (source-resistor $R_s$), and consequently the control voltage $U_{gk}$ ($U_{gs}$) amounts to –1,2V as long as the input voltage $U_e$ remains at zero. For guitar amps, the input impedance $R_e$ is often 1 MΩ, and the series resistor $R_g$ often amounts to 34 kΩ (two 68-kΩ-resistors in parallel), while the plate-resistor $R_a$ will be between 100 kΩ and 200 kΩ.

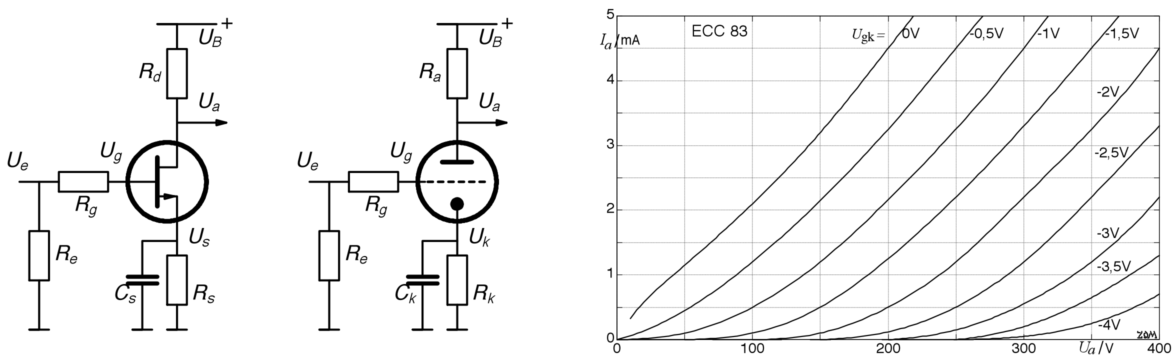


**Fig. 10.1.1:** Input-circuit of a tube amplifier (center) compared to a FET-amplifier (left). The right-hand picture shows typical characteristics (data-sheet of the double-triode-tube ECC83). The term “control voltage” is used in various ways – here, the grid/cathode-voltage and the gate/source-voltage is meant.

At the operating point (i.e. without drive signal, $U_e = U_g = 0$), the control voltage $U_{gk}$ ($U_{gs}$) is (at e.g. -1,2 V) negative for both circuits. Positive (i.e. less negative, e.g. -1V) control voltages make both amplifying elements conduct better: plate-(drain)- and cathode-(source)-currents rise. Without any cathode-(source)-capacitor, the cathode-(source)-voltage would consequently increase and thus counteract the drive signal, effectively causing negative feedback and decreasing the gain. Since early guitar amps had to make do with few tubes, high gain was required and such a negative feedback was uncalled for. Therefore, the cathode-resistor was bridged via an electrolytic **capacitor** (typically 25 µF) eliminating any AC-voltage at the cathode (within the relevant frequency-range): $C_k$ acts as an AC-short. With increasing input voltage $U_e$, the plate-current rises, and this increases the voltage across the load resistor $R_a$ such that – for a constant supply-voltage $U_B$ – the output voltage $U_a$ decreases. An AC-voltage at the input will cause an amplified, opposite-phase AC-output-voltage shifted by a constant DC-voltage (e.g. 250V – 100kΩ·0,8mA = 170V). The achievable voltage gain depends significantly on the type of tube: the often-used **ECC83** allows for an **AC-voltage-gain of about -50**.

 

The AC-voltage at the plate is out-of-phase with the grid-AC-voltage – which is why occasionally we find a **"minus"-sign** ($v$ = –50) in the gain specification. It would also be possible to define the voltage gain as the quotient of two RMS-values: now we would always get a positive gain-factor, e.g. $v$ = +50 (RMS-values are always positive). Still, even for positive gain specification, the plate- and the grid-ac-voltages will remain out-of-phase – at least for the common-cathode-configuration (cathode ac-connected to ground) that is ubiquitous in pre-amplification stages in guitar amplifiers.

The **voltage gain** actually obtainable with a tube circuit depends on the circuitry, on the power-supply, and on the individual tube. The **open-loop gain** (designated $\mu$ or $u$) given in data books characterizes a very specific operational state (no load at all at the output) that does not occur for a typical preamp stage. Both the plate resistor (also called load resistor) connected between plate and supply-voltage, and the input impedance of the subsequent amplifier stage, reduce the theoretical voltage gain to the level of the real *closed-loop gain* (often simply called *gain*). For the ECC83 (a typical preamplifier tube), an open-loop gain of $\mu$ = 100 (or –100) is given; the closed-loop gain that actually obtainable is smaller: typically, 20 … 50 may be expected. Since tube-data change their characteristics as they age, the gain does not remain constant over the years. Tube production is sometimes subject to considerable tolerances (electrode material, wiring, cathode coating, etc.), the gain of two off-the-shelf ECC83 may easily differ by 10% to 20%, and even larger tolerances are not unheard of.

To analytically describe the function of an amplifier tube, simplifications are required. Typical **models for tubes** are based on the following idealized modeling laws:

Driving a tube does not require any power (the input impedance is practically infinite); the tube is a linear and time-invariant system; the upper cutoff frequency is so high that the (low-pass-limited) signal from the guitar does not receive any additional filtering; "the" tube data are found in the tables of the data books.

**None of these assumptions are, however, applicable to typical guitar amplifiers** – at best, they are merely useful in the framework of a rough orientation. The following chapters are a short description of those tube-characteristics that are of particular importance for guitar amplifiers. Included are typical concepts for circuits, as well. Standard text-books [e.g. Barkhausen, Schröder, RCA-handbook] give supplemental basic knowledge. It is however vital to consider that, while the classic standard works discuss in detail and to some extent very theoretically the operational behavior of the tube, they do not mention with a single word the "abuse" (i.e. the umpteen-fold overdrive) that is regular practice in guitar amps. Modern text-books concentrate on semi-conductors and special tubes (technical tubes), and are not helpful in the context of guitar amps. Those books that in fact do discuss the idiosyncrasies of a tube-powered guitar amp are often kept rather general; they hardly offer any measurement results and rarely any theoretical calculations. In the worst case, mere assumptions are circulated as they are now found almost deluge-like on the Internet. "*The cathodyne circuit sounds much tighter than the SEPP or the long-tail because already Leo Fender introduced it in the 5E6a*" N.B.: here, it appears that this circuit sounds tighter (whatever that means) not because of any technical characteristic but because it is spiritually connected to Leo Fender …

 Translated by Tilmann Zwicker