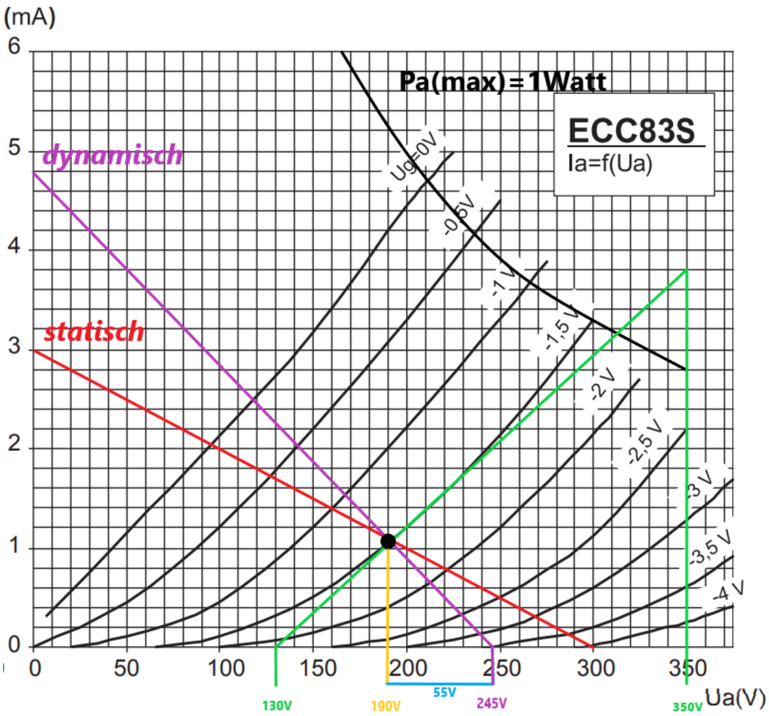
Calculating the Preamp Tube

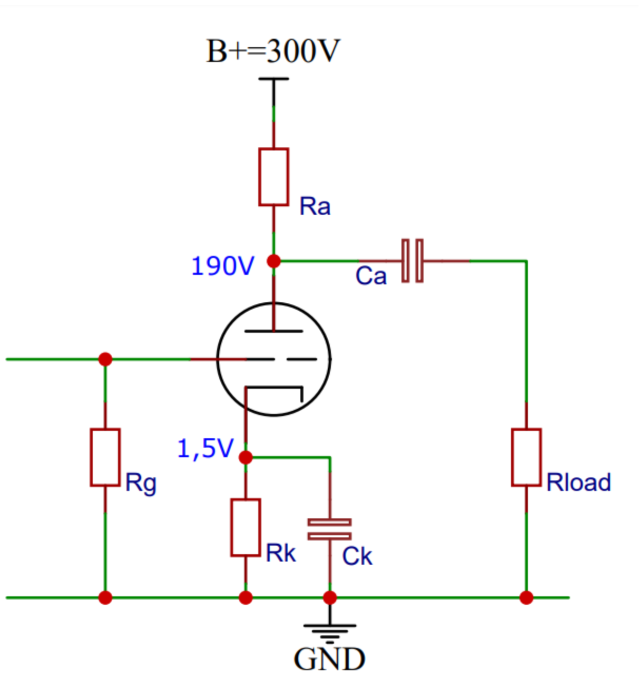
To understand tubes, you need to learn how to work with load line diagrams. These diagrams help in designing amplifier circuits and show how basic components interact.

Ask yourself questions such as:
• What happens if I increase the anode load resistor?
• What happens when I lower the anode voltage?
• How do I adjust my bias point?

The goal is:
• Maximum amplification.
• Minimal THD (Total Harmonic Distortion).

Note:
These graphs serve as general guidelines for a specific tube type, but deviations of 10 to 15% are normal. No two tubes are identical, even from the same brand or batch. When calculating resistors, such as the cathode resistor, choose the closest available value or combine resistors to achieve the correct value.





The Calculation

Given:

- We have a graph of the ECC83 and a supply voltage of **B+ = 300V.**
- The bias point **(Vgk)** is set at **-1.5V**, with a corresponding **Ia (bias current)** of **1.1 mA**.
- Choose the bias point so that the sinusoidal amplitude is equal in both the positive and negative directions.
- The distances between **Vgk = -1V, Vgk = -2V, and Vgk = -1.5V** should be as equal as possible.
- The load resistor **(Rload)** is **100 kΩ.**

Note:

Rg is usually also the **Rload** of the previous amplifier stage.

The Static Load Line

We start by drawing a line from **300V (B+)** through the selected bias point to the Y-axis. Next, we determine the anode **resistor (Ra),** which establishes the static load line **(red line).**

$$R_a = \frac{B+ - Vak\ (bias)}{Ia\ (bias)} = \frac{300\ V - 190\ V}{1{,}1\ mA} = \frac{110V}{1{,}1\ mA} = 100K\Omega$$

This is also allowed if no **bias point** has been chosen yet. Of course, the bias point must be placed somewhere on the **load line**.

$$R_a = \frac{B+}{Ia} = \frac{300\ V}{3\ mA} = 100K\Omega$$

The power dissipation of the **anode resistor (Ra)** is calculated using:

$$P_{Ra} = U * I = 110V * 1{,}1mA = 121\ mW$$

Choose a 600 mW resistor to ensure it can handle the power dissipation safely.

The **cathode resistor (Rk)** can now be calculated:

$$R_k = \frac{Vgk}{Ia\ (bias)} = \frac{1{,}5\ V}{1{,}1\ mA} = 1{,}36K\Omega$$

Use a standard resistor value of **1.2kΩ** or **1.5kΩ**, depending on the desired bias accuracy. Alternatively, you can create a more precise resistance by combining resistors in **series** or **parallel**.

Dissipatie van de Kathode weerstand **(R_k)**:

The power dissipation of the **cathode resistor (R_k)** is calculated using:

$$P_{Rk} = U * I = 1{,}5\ V * 1{,}1\ mA = 1{,}65\ mW$$

The Dynamic Load Line (Rdyn)

So far, the amplifier stage has not needed to drive any other components, but this is not realistic. An amplifier stage that drives the next stage affects the operation of the preceding stage. This influence is represented by the **dynamic load line (Rdyn)**.

Calculating the Dynamic Resistance

The **dynamic resistance** is determined by the **parallel combination** of **Ra** (anode resistor) and **Rload** (the input resistance of the next stage):

$$R_{dyn} = R_a \,||\, R_{load} = \frac{Ra * Rload}{Ra + Rload} = \frac{100K * 100K}{100K + 100K} = \frac{10000K}{200K} = 50K\Omega$$

Choosing **Rload** to minimize its effect on the tube's operating point:

- **Rload** should be as large as possible.
- A general rule of thumb is **Rload ≥ 5 × Ra**, though this is not always achievable.
- Typically, **Rload** is around **1MΩ** (the grid resistor **Rg** of the next stage).
- If **Rload** is too low, it will significantly influence the tube's static bias point.

Example Case:

For clarity, in this example, **Rload is set equal to Ra** to illustrate the effect. In real designs, choosing a **higher Rload** improves gain and linearity. Always check the tube specifications of the next stage to determine the maximum allowable **Rload**.

For the slope of the dynamic load line, we need two points. The first point is the bias setpoint. The second point is calculated.

$$Va = R_{dyn} \times I_{a\,(bias)} = 50K\Omega * 1{,}1\ mA = 55\ V$$

The second point is set at **190 V + 55 V = 245 V** on the zero line. Draw a line from the X-axis to the Y-axis. Here, it can be seen that the dynamic load line is steeper than the static load line, which usually results in more distortion. Therefore, the load resistance **(Rload)** should be chosen as large as possible. However, this is not always feasible. For example, when using a 300B tube with fixed bias, the grid resistance **(Rg)** must not exceed **50K**, as the tube would otherwise start to drift.

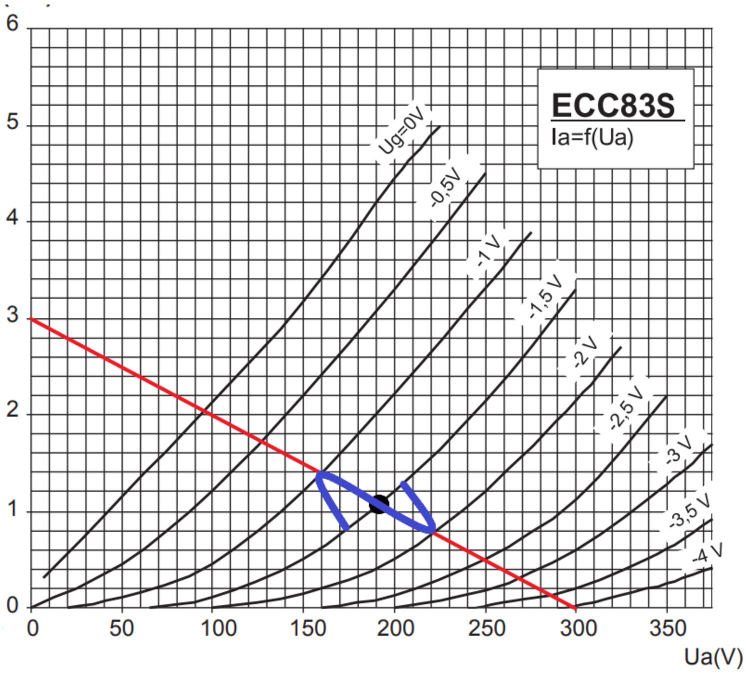
The internal resistance of the tube (Ri)

Draw a line as parallel as possible to the Ug characteristic, with the intersection at the chosen bias point.

$$r_i = \frac{Va}{Ia} = \frac{350\,V - 130\,V}{3{,}8\,mA} = \frac{220\,V}{3{,}8\,mA} = 57{,}8K\Omega$$

The amplification:

$$\mu = \frac{\Delta\,Vak}{\Delta\,Vgk} = \frac{220\,V - 160\,V}{2\,V - 1\,V} = \frac{60\,V}{1\,V} = 60$$



Calculating the Distortion:

It is essential to choose the bias point so that the amplitude of the sine wave is as equal as possible in both the positive and negative directions relative to the bias point. This results in a symmetrical waveform, as shown in the image below.

At **Vgk = -1V**, the voltage is **160V**.
At **Vgk = -1.5V**, the voltage is **190V**.
At **Vgk = -2V**, the voltage is **220V**.

The difference between **220V and 190V** is **30V**.
The difference between **190V and 160V** is **30V**.

This indicates a linear response, meaning the amplification is symmetrical, which helps minimize distortion.

Now you can also calculate the distortion.

$$THD_2 = \frac{30V-30V}{30V+30V} * 100 = 0\%$$

Calculating the Coupling Capacitor (Ca):

A general rule of thumb is that the -3dB frequency point is set at 3Hz.
When calculating Ca, first determine the output impedance of the amplifier stage. However, this value is usually so small that it can generally be neglected.

$$r_{out} = R_a // r_i = \frac{Ra * ri}{Ra + ri} = \frac{100K * 57{,}8K}{100K + 57{,}8K} = 36{,}6K$$

$$C_a = \frac{1}{2 * \pi * (Rout+Rload) * f-3dB} = \frac{1}{2 * 3{,}14 * (36{,}6K+100K) * 3\ Hz} = 388\ nF$$

Calculating the Cathode Bypass Capacitor (Ck):

$$C_k = \frac{1}{2 * \pi * Rk * f-3dB} = \frac{1}{2 * 3{,}14 * 1{,}5K * 3\ Hz} = 35\ \mu F$$

These values represent the minimum required capacitance to avoid affecting the frequency response. You can choose a larger capacitance if desired. In practice, a commonly available capacitor value is often used.

Miller Capacitance

This is another important factor to consider, as it can significantly impact the frequency response, especially in the high-frequency range.

A high Miller capacitance can reduce the amplifier's bandwidth, requiring adjustments in circuit design, such as lowering the anode resistor value or adding a cathode follower stage to reduce gain and input capacitance.

Every tube has some parasitic input capacitance, and triode tubes, in particular, tend to have relatively high input capacitance.

If we take the **ECC83** tube as an example and refer to its datasheet, we can find several input capacitance values that influence the circuit's behavior. The **Miller effect** amplifies this capacitance, which can limit the amplifier's high-frequency response.

Direct Interelectrode Capacitances (per triode)			
Grid to Cathode and Heater	C_g	1.6	pF
Plate to Cathode and Heater	C_a	0.33	pF
Grid to Plate	C_{ga}	1.7	pF

We take the most important capacitances: **Cg** (grid-to-cathode capacitance) and **Cga** (grid-to-anode capacitance).

At first glance, these values may seem small, but the anode voltage is the amplified version of the grid voltage. Due to the **Miller effect**, the effective input capacitance is significantly increased.

If we assume an effective gain of **60** and an input signal of **1V RMS**, the formula for the effective input capacitance becomes:

$$C_{in}=C_g+C_{ga}*(A+1)$$

Additionally, extra capacitance must be added due to the physical proximity of the tube's connection pins. The anode and cathode pins are located close to the grid pin, contributing approximately **1 pF each** to the total capacitance.

$$C_{in}=2{,}6+2{,}7*(60+1)$$

$$C_{in}=167{,}3pF$$

We know that the output impedance of the previous stage is (**Rout=36.6K**). If applicable, add the value of a grid resistor to this. This allows us to calculate the frequency range.

$$f-3dB=\frac{1}{2*\pi*Rout*Cin}=\frac{1}{2*3{,}14*36{,}6K*167{,}3pF}=26kHz$$

We see that this is still just above our hearing threshold. If we were to add another amplification stage, we would run into problems.

What can we do to minimize the Miller effect?

- **Reduce the output impedance of the previous stage.** This can be achieved by using a different tube with lower internal resistance or by implementing a cathode follower circuit.
- **Reduce the effective gain of the tube.** This can be done by using local negative feedback or simply by choosing a tube with a lower effective gain.