Measuring of Tubes – Heating with DC or AC current ?

Report about the experiments of Helmut Weigl

Preamble:

In connection with the development of my computer controlled tube measuring device “RoeTest” the question arose whether there are different sources required for the heating when taking measurements. Especially if in addition to a DC heating source also an AC heating source were required or if this is unnecessary (the complexity for a continuous adjustable and automatic controlled AC heating supply would be enormous).

I have read in several publications and in forums that different heater sources were required when measuring tubes. Along with a DC heating source there should also be an AC heating source for direct heated tubes that are designed for AC heating. Otherwise the measured values would depart from the manufacturers data (tube tables).

But I did not find concrete arguments for that.

What tubes need supposedly mandatory an AC heating source ?

Tube type	**DC heating possible?**	**Rationale**
Indirectly heated tubes	yes	The type of heating is irrelevant as the cathode is insulated from the filament
Directly heated tubes battery tubes or DC heating	yes	These tubes are designed for DC heating
Directly heated tubes for AC heating	no	When heating these tubes using DC different measure values will be the result. The table values for AC heating do not apply any longer

Is it possible to heat directly heated tubes designed for AC heating also using DC heating?

In principle yes. But that would yield other measured data for anode and screen grid current. The measured values would depart from the data sheets ore tube tables. For these cases either different tables for DC heating would be required (I did not find any) or the values have to be found experimentally (in that case a larger number of particular tubes in mint condition are needed, which I normally do not have).

Questions that have to be discussed:

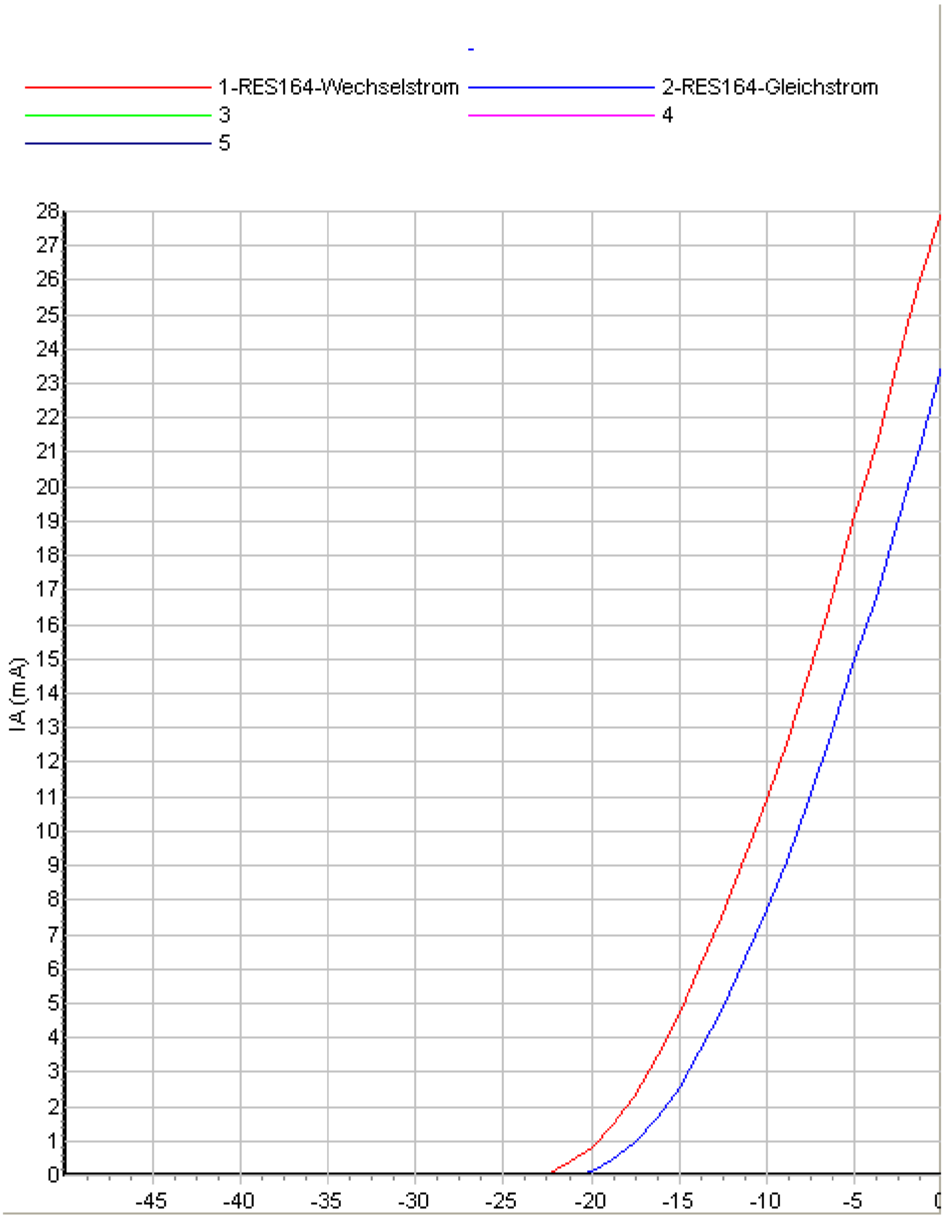
- How do the measuring values differ when using AC or DC heating ?
- What could be the reason for the different behavior?
- Is there a particular principle?
- Would it be possible using this principle to convert the measured values from DC heating to AC heating, or change the measuring mode in such a way as to compare the measured values with the tables for AC heating?
- Can we do without using an AC heating source?

How do the measured values differ between AC and DC heating ?

The first step is to find out whether and how the measured results differ when using different heating methods. For this task the same tube is measured using different heating methods and the characteristic curves are compared.

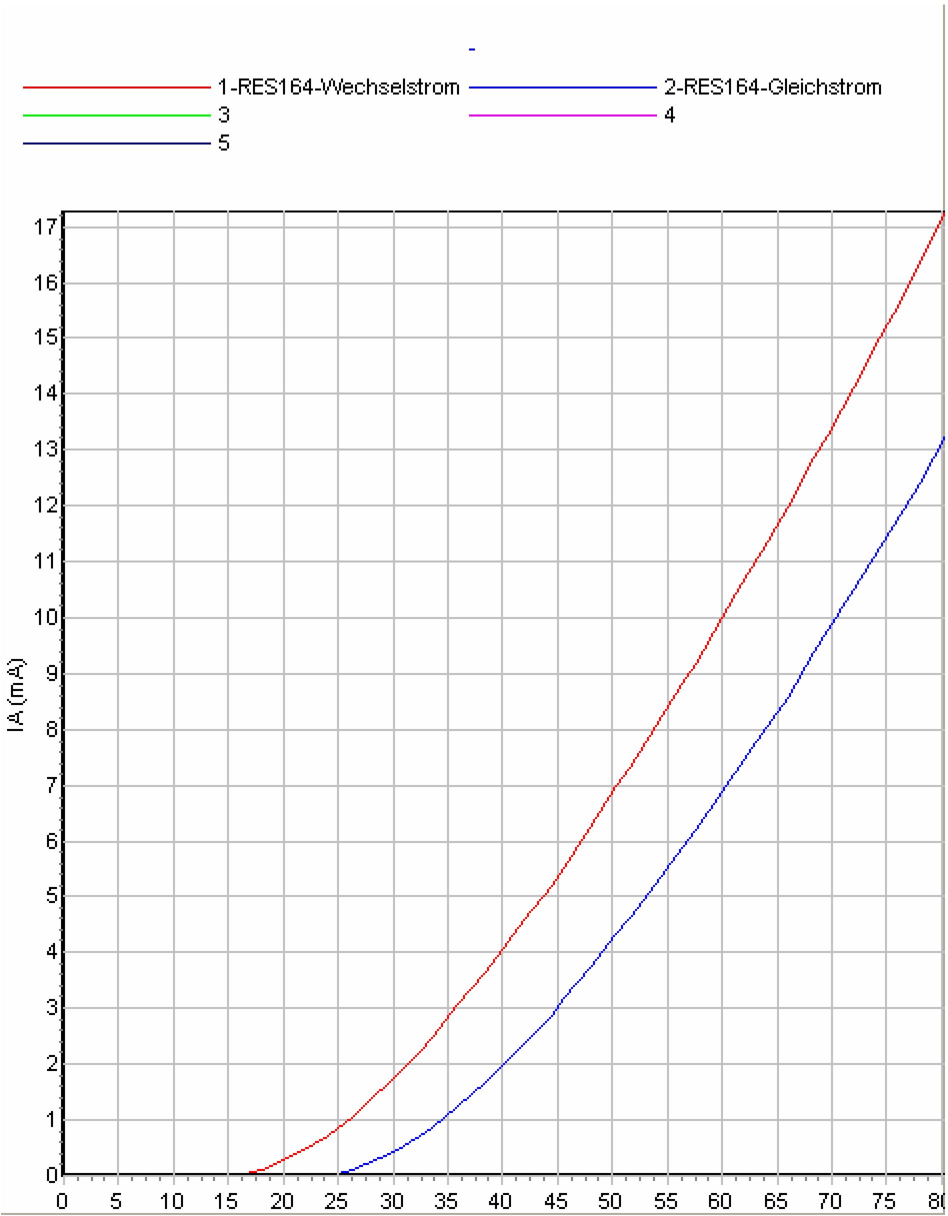
I measured 3 different tubes (AL1, RES164 and RES964) for testing that. The results were similar. In the following I will show some results and discuss them.

1. G1- Characteristic curve:



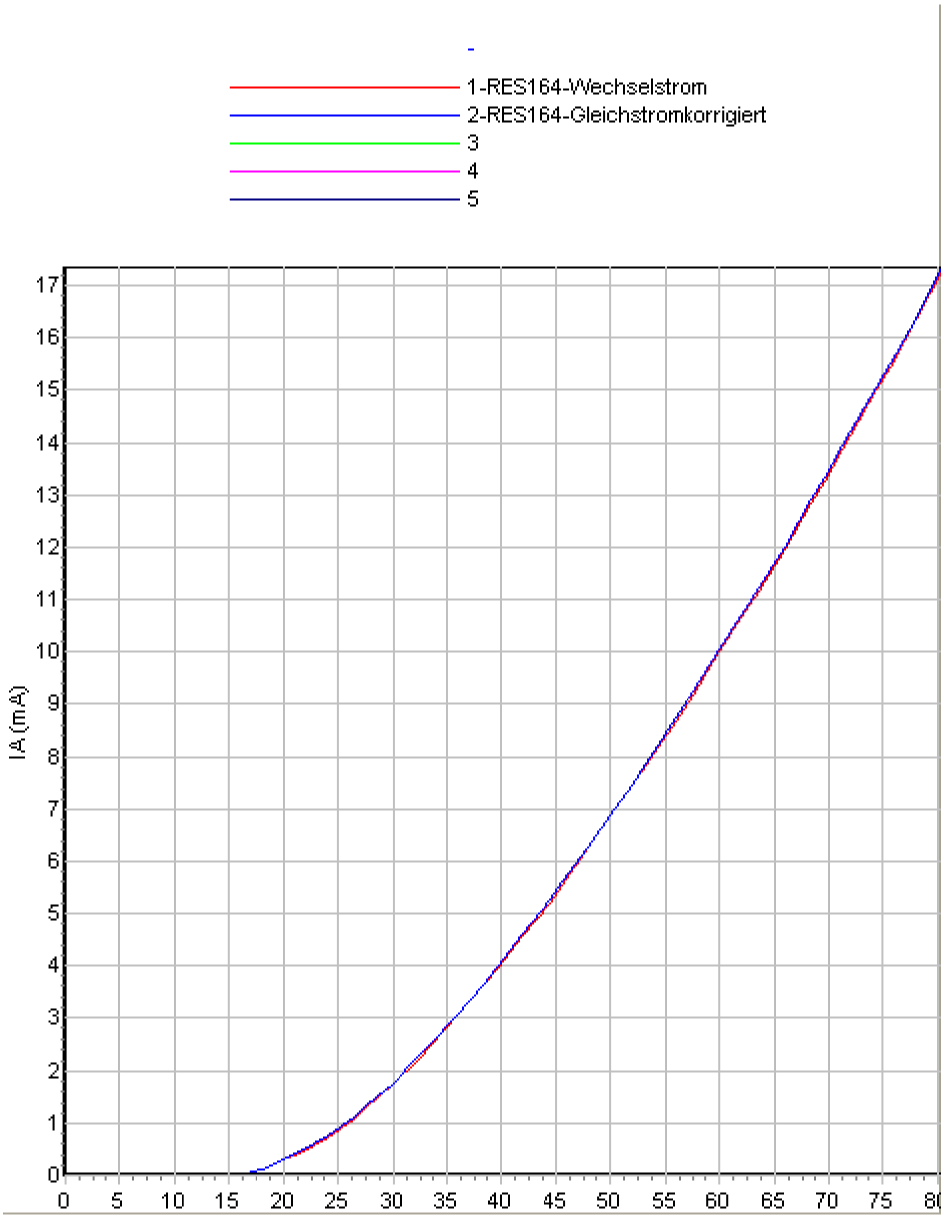
Result: When using DC heating (blue curve) the anode current is somewhat lower compared to AC heating (red curve). The characteristic curve is evenly shifted to the right.

2. G2-Voltage curve:

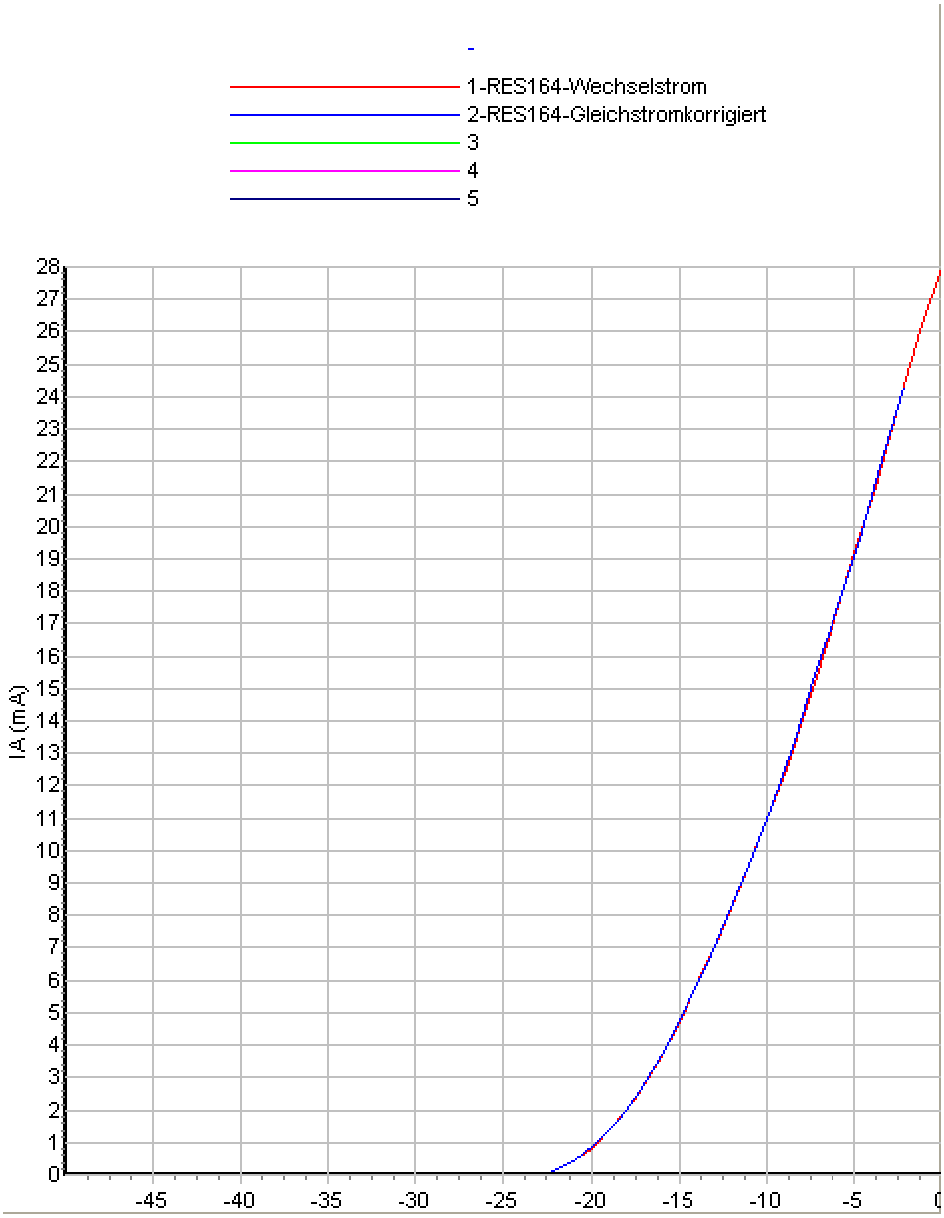


Result: As already seen with the G1 characteristic curve the anode current of the G2 characteristic curve is lower at DC heating compared to AC heating.The characteristic curve is also shifted to the right.

When shifting the characteristic curve for DC heating to the left and superimpose it with the characteristic curve for AC heating you get the following picture:



G1-Characteristic curve:



Result: The measured characteristic curves are identical for AC and DC heating and merely shifted to the right (lower values) when using DC heating.

This experiment promises to find a conversion possibility from DC heating to AC heating.

What reasons could be responsible for the different behavior?

Heating Power:

For testing we use a filament-only “tube” = lighting bulb. Heating with DC current or AC current (same rms-value) yields no difference. By visual judgment the bulb glows with the same intensity. Therefore the filament must also have the same temperature.

→ no effect for the measured values

Modulation of Temperature:

In theory the temperature of the filament fluctuates with double the frequency of the AC current when using AC heating. But the thermal inertia of the filament acts contrary to that

→ the influence to the measuring results seems to be unrealistic

Different Distribution of the Heating Voltage across the Filament:

a) DC Heating

Distributed along the filament there are different potentials at each point of the filament (form -heater supply to + heater supply). Normally the negative pole of the heating voltage is also the ground=reference point. There is a separate characteristic curve for each point of the filament. From these single characteristic curves the total characteristic curve of the tube is derived (see Barkhausen).

b) AC Heating

The heating voltage swings around the zero point from minimum to maximum with double of the heater supply frequency. Averaged the same total characteristic curve results.

→ no effect for the measured values

Cathode Current increases the Heating Current:

The current through the cathode is added to the heating current and rises the temperature of the filament. With DC heating the temperature rise at the negative pole of the filament is larger compared to the positive pole of the filament.

→ Generally the heating current is significantly larger than the cathode current (according to Barkhausen the heating current shall be at least 5 times larger than the cathode current) so the temperature rise is only minimal.
→ The temperature rise only affects the saturation area. Tubes are normally operated in the space-charge region. For this reason the effect can be neglected.

Temperature changes created by the departing of electrons:

Depending on the construction of the tube it could be possible that the filament temperature rises or drops. According to Barkausen this effect can be ignored.

Experiment:

To confirm the results from above the following experiment is done. The tube's characteristic curve is recorded both using AC heating and DC heating. In contrast to the recent experiments a symmetrical circuit is used. An electrical midpoint is formed both for AC and DC heating and connected to ground (in the experimental setup a transformer with a middle tap is used for AC, respectively a symmetric DC heating supply).

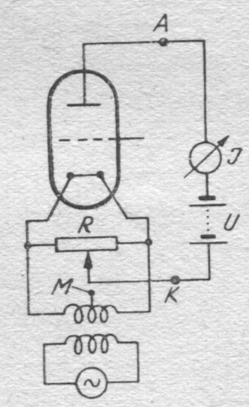
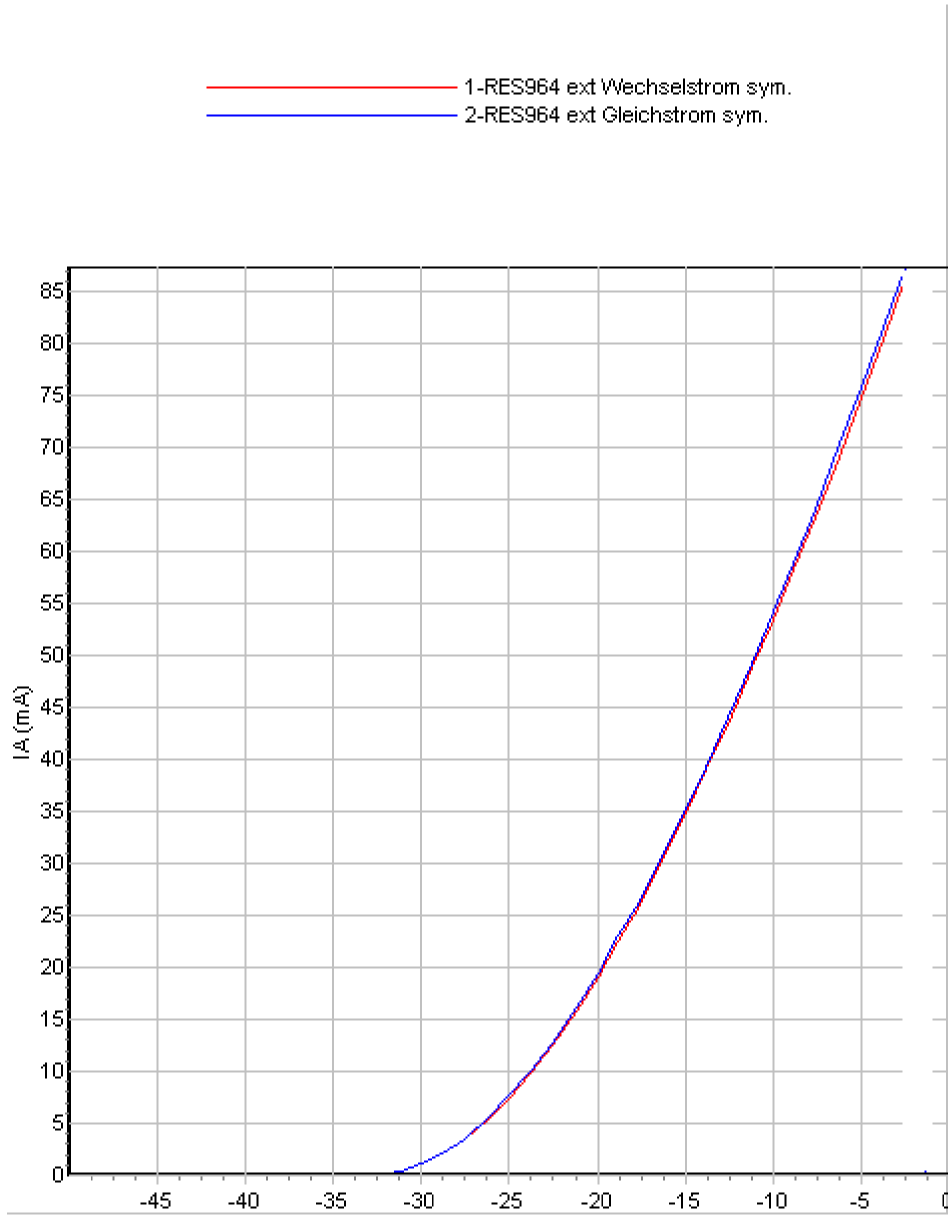


Bild 5 m. Künstliche Mitte bei direkter Heizung mit Wechselstrom.

measured characteristic curves:



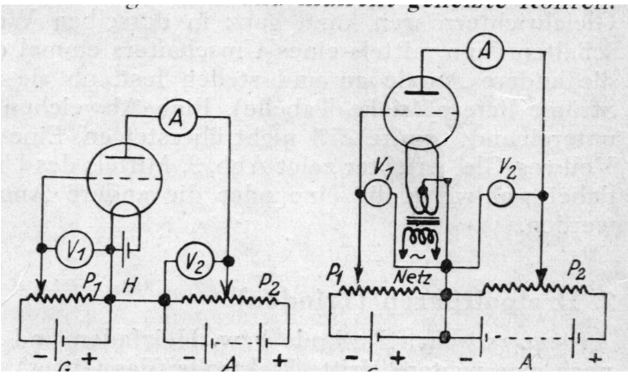
Result: The characteristic curves are identical. The claims from above are confirmed. From this results follows that in practice it does not matter if the tube is heated using AC or DC current as long as the circuitry is identical. If there are differences at all these are so small that they can be neglected.

This experiment also shows the reason for the difference in the characteristic curves in the previous experiments:

Different circuitry between AC and DC heating of the tube:

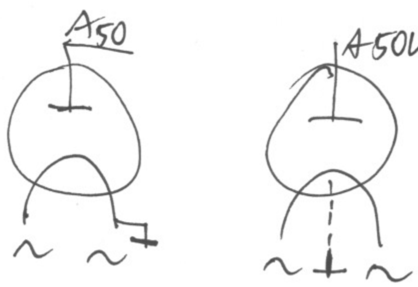
With DC heating in the normal case one end of the filament is connected to the circuit ground. Normally the negative pole of the heater voltage is connected to ground.

If the tube is heated using AC current in the same circuit there would be a large mains hum. For this reason an electrical mid is built between the filament ends (tapped transformer, resistors – so called 'Entbrummer'-, tapped filament) and this is grounded. For illustration see the following picture (on the left side DC heating, on the right side AC heating).



With AC heating the same potential is located along the filament (seen from a DC view point). The voltage swings around <u>0 volt</u> (from maximum to zero and then to the minimum).

B



bei Wechselstromheizung liegt am gesamten Heizfaden identisches Gleichstrompotential an (die Spannung schwankt um 0 Volt)

With <u>DC heating</u> the voltage at the left
filament connection is 0 volt,
the voltage at the right connection is the full heating voltage. At 4 volt heating voltage the average voltage at the filament is 2 volt. <u>The zero point is shifted by half of the heating voltage.</u> The anode and all grids have a voltage to the middle of the filament that is reduced by half the heating voltage with DC heating!

ACHTUNG: Der folgende Text gehört in obiges Fenster (rechts); ich kann das nicht edieren! With AC heating there is identical DC potential along the filament (the voltage swings around 0 volt)

To get the same measuring results with DC heating as with AC heating one either has to

- generate the same potentials as with AC heating (also use an electrical midpoint for DC heating, see experiment above) or
- change the voltages at anode and all grids by + ½ of the heater voltage

Experiment for 2nd method: (RES964, Heater voltage 4 V)

	AC Heating	DC heating	**DC heating according to 2.**
Experimental setup	**Electrical middle using transformer tap**	Negative pole of heater connected to ground	**Negative pole of heater connected to ground, Electrodes +1/2 heater voltage**
Anode voltage	**250 V**	250 V	**252 V**
Screen grid voltage (G2)	**250 V**	250 V	**252 V**
Grid voltage (G1)	**-15 V**	-15 V	**-13 V**
Measured anode current	**34,75**	27,25	**34,75**
Measured screen grid current	**6**	4,7	**6,05**

Result: The measured valued are the same for DC and AC heating when using the same voltages measured to ground, i.e. increasing the voltages of all grids and the anode by + ½ the value of the heater voltage.

Limitations for this measuring method:

The grid voltage G1 cannot be positive. Therefore with DC heating using method 2. the grid voltage can only be a minimum of *-½ of the heater voltage* (at 4 volt heater voltage the minimal grid voltage is – 2 V ((-2) + 2 = 0V measuring voltage). It is not possible to make measurements / record characteristic curve at a grid voltage of 0 V.

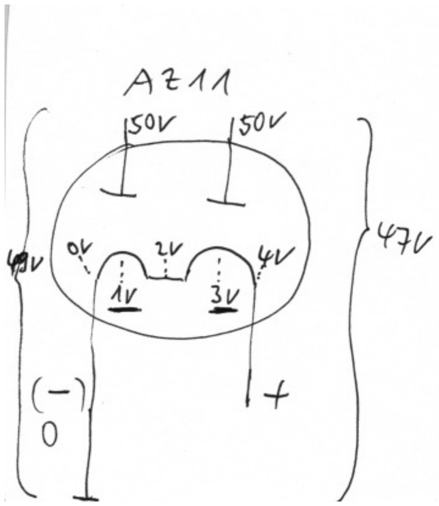
The heater voltage must be exactly controlled either the working points will change!

Rectifier Tubes:

In principle the same rules apply as with other tube types. Normally there is no electrical mid of the heater supply connected to ground in common circuits.
In the normal case one end of the filament respectively the heater coil of the transformer is connected to the anode coil of the transformer. When measuring with AC heating it does not matter which end of the filament is connected to ground or if an electrical mid is built. It is reasonable to use an electrical mid when taking measures and compensate the 'hum' this way.

When using DC heating the anode voltage has to be increased by ½ of the heater voltage to get the same conditions.

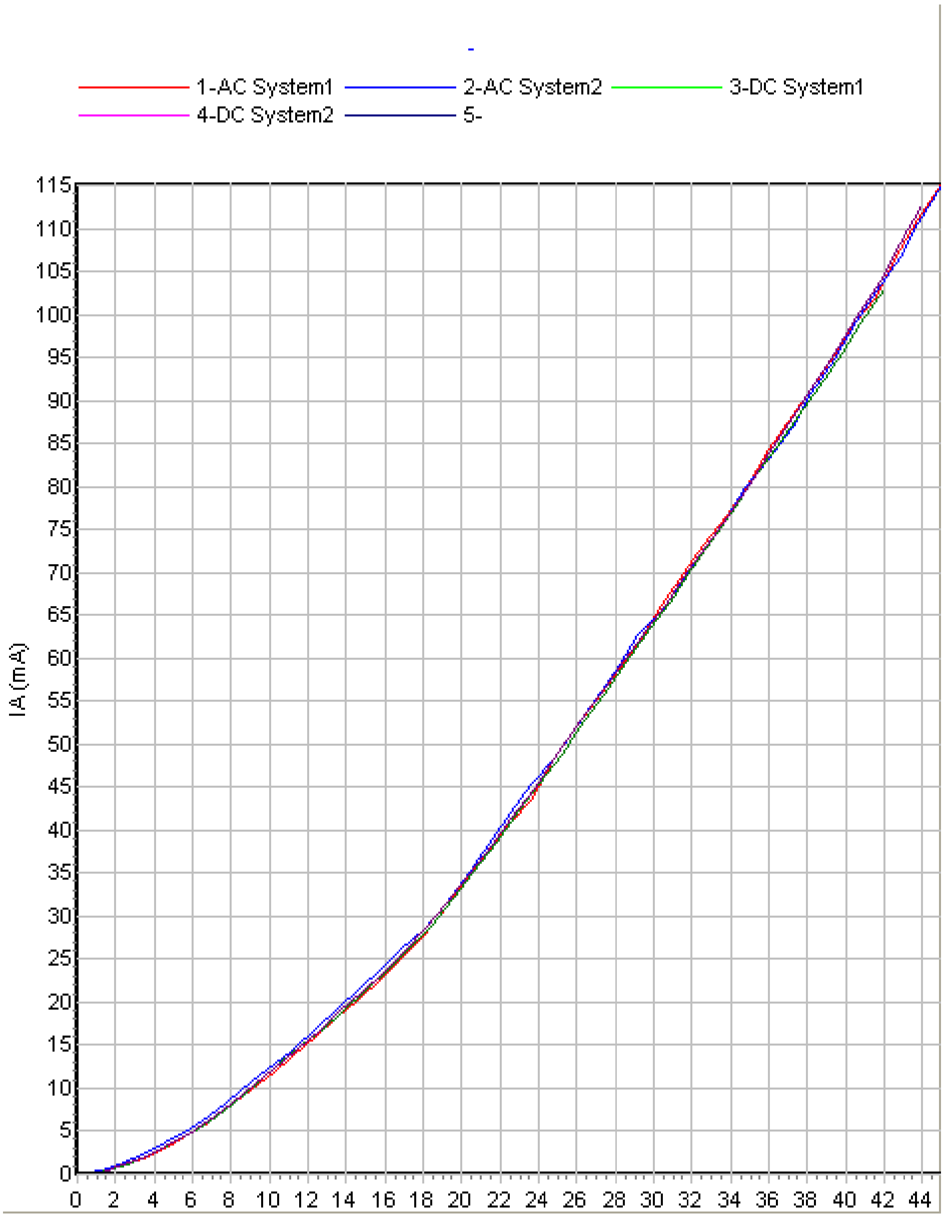
Rectifier tubes with 2 systems (e.g. AZ11) differ so one system is at the negative end of the filament the other system at the positive end of the filament. Due to that with two equal tube systems and DC heating – contrary to AC heating – different anode currents will be measured. Also for this case it is possible to create the same conditions as with AC heating. But different anode voltages have to be applied to the two systems:



At the left system the filament in average has a potential that is 1V higher measured against ground. The right system in the example above there is a potential that is 3V higher.

To create the same conditions as with AC heating the anode voltage of the left system must be increased by 1V (=¼ heater voltage), the anode voltage of the right system by 3V(=3/4 heater voltage).

In the following the characteristic curves of an AZ11 using AC heating, DC heating and simulation (the tested AZ11 had 2 nearly same systems): The characteristic are identical:



Conclusion:

1. It is quite possible to heat direct heated tubes designed for AC heating with DC current and to get the same measuring results as with AC heating. The measured values then can be compared with manufacturer data or tube tables.
2. Converting the measured values by hand – especially recording the characteristic curve – is tedious and error prone. A computer aided conversion solves this problem.
3. When creating the same measuring conditions an AC heating supply is not needed.

Literature:

Elektronen-Röhren, H. Barkhausen, 1. Band, Allgemeine Grundlagen, Fünfte Ausgabe, 1945

Messen und Prüfen von Röhren und Einzelteilen, Rolf Wigand, 2. erweiterete Auflage, 1934

Handbuch der Radio- und Fernsehreparaturtechnik, Band 1 Radio Service, W. Diefenbach, 1961

Radios von Gestern, Ernst Erb, 3. Auflage 1997

Röhren Taschenbuch Bd. 1, W. Beier, 8. verb. Auflage 1958

Röhren Taschenbuch Bd. 2, W.Beier, 2. verb. Auflage 1958

All measurements were taken using Helmut's Computer Tube Testing / Measuring / Regeneration device "RoeTest".