BBC ENGINEERING TRAINING information sheet (Preliminary)

THERMIONIC VALVES

1. INTRODUCTION

Although the transistor has taken over from the valve in many applications, there are still a number of strongholds where the valve is still holding out. Apart from some old equipment which has not been replaced by transistorised versions, there are certain fields, such as high power transmitters, where transistors cannot be used. There are also other examples of thermionic emission such as cathode ray tubes used in oscilloscopes, picture monitors, and camera tubes where the same principles apply.

This handout covers thermionic emission and valve characteristics.

2. THERMIONIC EMISSION.

Each atom of a substance consists of a positively charged nucleus surrounded by negatively charged electrons. In metal conductors the electrons are free to move about within the metal, from atom to atom. They are stopped from leaving the conductor by an energy barrier. Unless they have sufficient energy to overcome this barrier they will remain in the conductor.

This principle is similar to the problem of a rocket leaving the earth. Unless it is given sufficient energy to overcome the earths gravitational force it will fall back again.

In the thermionic valve the energy is provided by heating the conductor. When a conductor is heated sufficiently, electrons will leave its surface. If they have nowhere to go then they will form a 'space charge' around the conductor. This space charge will now be negative while the conductor, having lost electrons, will be positive. Electrons from the space charge are now attracted back to the conductor, and are replaced by more leaving it.

3. THE DIODE VALVE

The diode valve consists of a cathode which is our 'heated conductor' and an anode in a vacuum. The cathode may be 'directly' heated by passing a current through it or 'indirectly' heated by a heating element which is insulated from it electrically.

If the value were not evacuated, ionisation of the air or gas particles would occur, disturbing the action of the diode.

If the anode is connected to the cathode a current will flow. This is due to the anode being more positive than the space charge. To cancel this current, the anode would require a small negative potential.

A positive potential on the anode will increase the current. A characteristic similar to that in figure 1(b) will result.

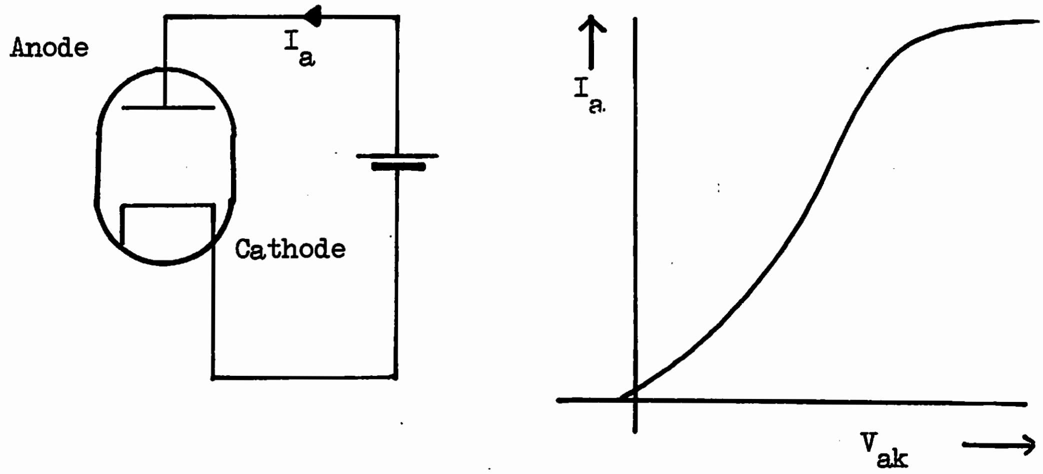


Figure 1: Thermionic Diode

The maximum value of the anode current is limited by the temperature of the cathode, causing the curve to flatten off.

4. THE TRIODE VALVE

4.1 Triode Characteristics

With the triode valve a control grid is interposed between the anode and cathode. This 'grid' is in the form of a wire mesh.

The control grid is normally held at a negative potential with respect to the cathode.

This negative potential provides a negative field which reduces the number of electrons which can get through the grid to the anode.

The characteristics, for a triode are normally shown as a set of 'anode characteristics' with separate lines for different grid potentials. (See figure 2).

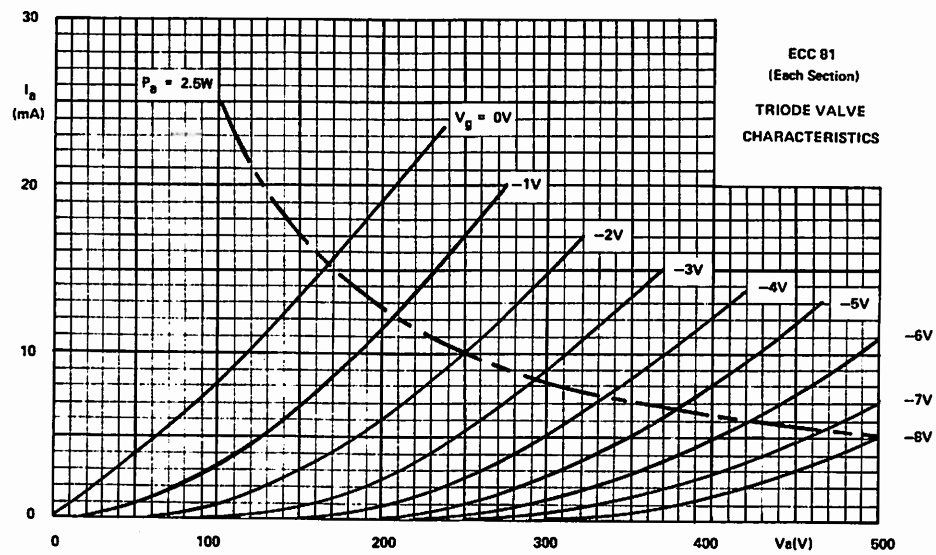


Figure 2: Typical Anode Characteristics for a Triode

4.2 Valve parameters

There are three basic parameters which can be obtained from the valve characteristics. These parameters are r_a, μ and g_m.

r_a - the 'anode slope resistance' of the valve.

This is the effective output resistance of the valve. As the valve is normally operated about a particular point on its characteristics, the anode slope resistance is derived from the slope of the characteristic at that point. (See figure 3).

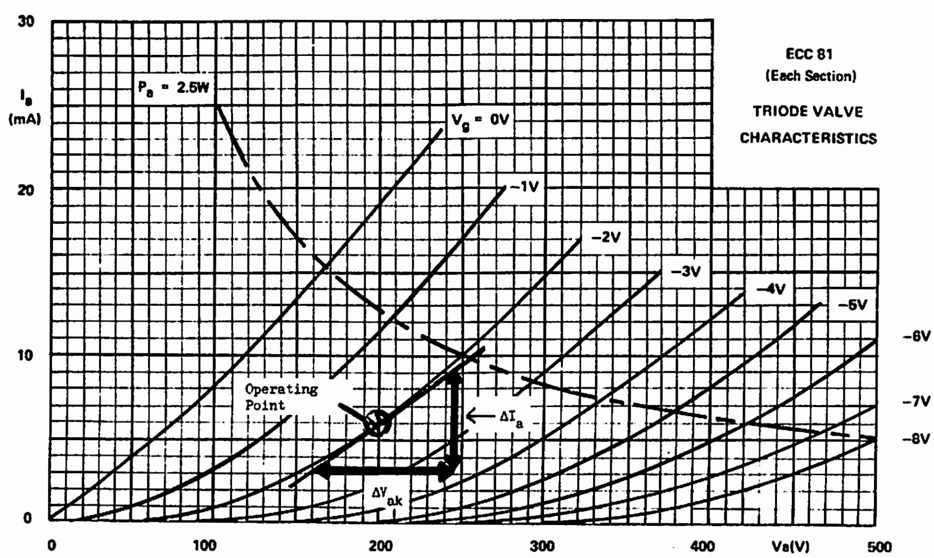


Figure 3: Obtaining r_a from the triode characteristics

r_a is the change in V_{ak} (ΔV_{ak}) caused by a change in I_a (ΔI_a) when V_{gk} is kept constant.

i.e. $$r_a = \frac{\Delta V_{ak}}{\Delta I_a} \text{ with } V_{gk} \text{ Constant} \qquad (1)$$

μ - the 'amplification factor' for the valve.

This is the change in V_{ak} (ΔV_{ak}) caused by a change in V_{gk} (ΔV_{gk}) when I_a is kept constant. It may be considered as the voltage gain when the valve is operated into an infinite impedance load, i.e. the 'Thevenin voltage gain'. It is also the maximum voltage gain which the valve can achieve for a given operating point. (See figure 4)

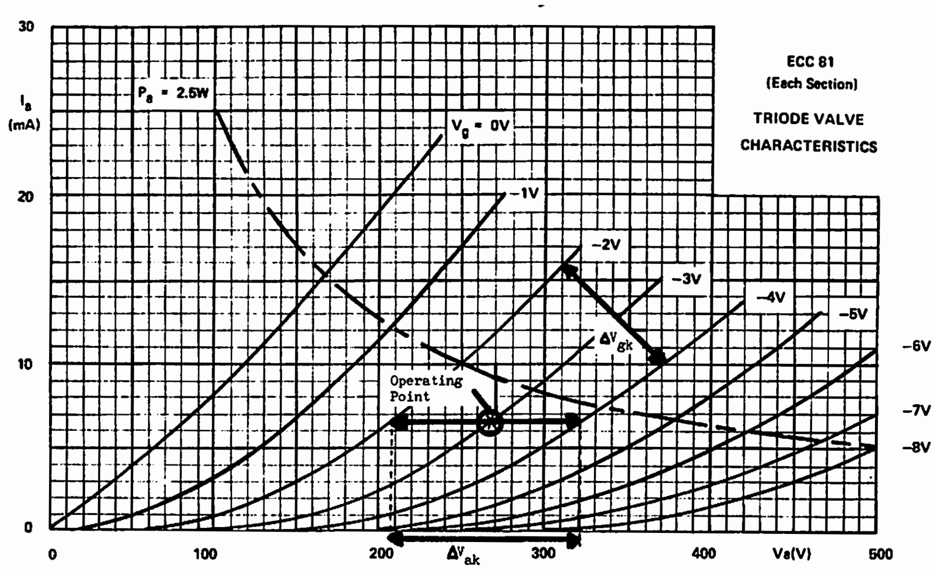


Figure 4: Obtaining μ from the triode characteristics.

μ is given by:-

$$\mu = \frac{\Delta V_{ak}}{\Delta V_{gk}} \text{ with } I_a \text{ constant} \qquad (2)$$

g_m the 'mutual conductance' for the valve. This is the change in anode current (ΔI_a) caused by a change in grid voltage (ΔV_{gk}) with the anode voltage kept constant. (See figure 5).

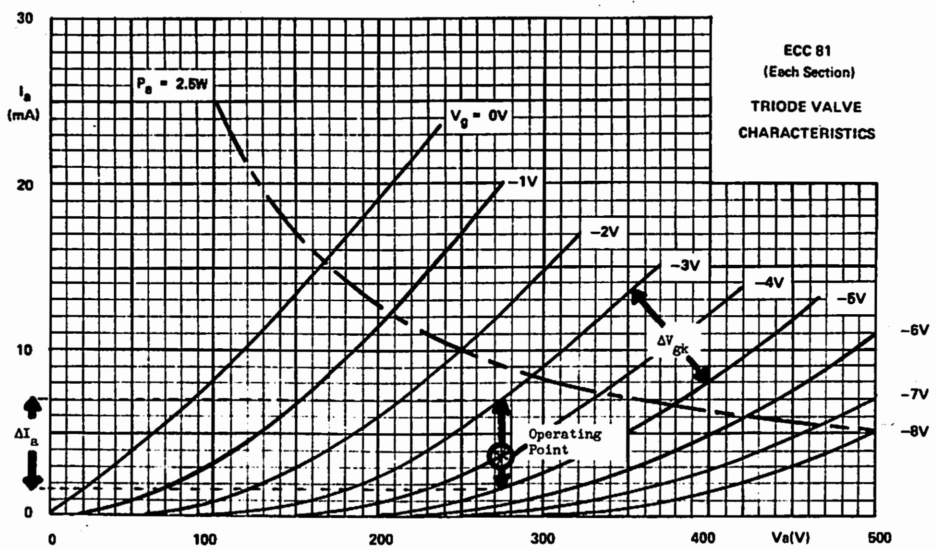


Figure 5: Obtaining g_m from the triode characteristics

g_m is given by:-

$$g_m = \frac{\Delta I_a}{\Delta V_{gk}} \text{ with } V_{ak} \text{ Constant} \qquad (3)$$

from equations (1), (2) and (3) we can obtain:-

$$g_m \times r_a = \frac{\Delta I_a}{\Delta V_{gk}} \times \frac{\Delta V_{ak}}{\Delta I_a} = \frac{\Delta V_{ak}}{\Delta V_{gk}} = \mu$$

$$\text{or } g_m \cdot r_a = \mu \qquad (4)$$

Appendix A shows the characteristics for one section of an ECC 81 double triode. The curve labelled P_a = 2.5W is the manufacturers maximum recommended power dissipation curve. The valve should be operated below this curve.

Problem 1

Derive r_a, μ and g_m from the ECC 81 characteristics about an operating point at V_{gk} = -1V, I_a = 10mA.

5. THE TETRODE VALVE

The tetrode valve was developed to provide more gain than the triode and also to screen the grid from the anode. The capacitance between the output (represented by the anode) and input (represented by the grid) of a triode is often a problem at high frequencies.
In the tetrode a second grid is interposed between the control grid and anode. This grid is then held at a high positive voltage to accelerate the electrons and is decoupled to a.c. to provide an electrostatic screen. (See figure 6).

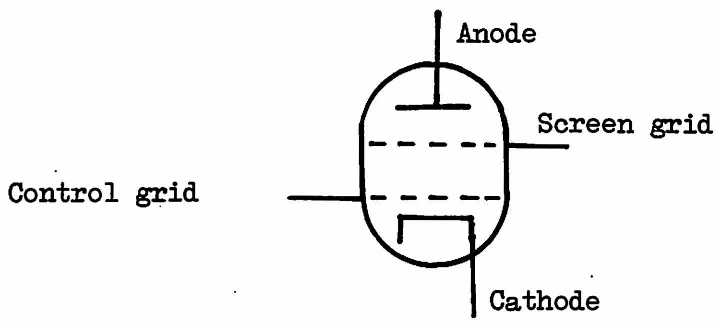


Figure 6: The Tetrode Valve

Unfortunately tetrode valves have characteristics which normally have a 'kink' in them. (See figure 7).

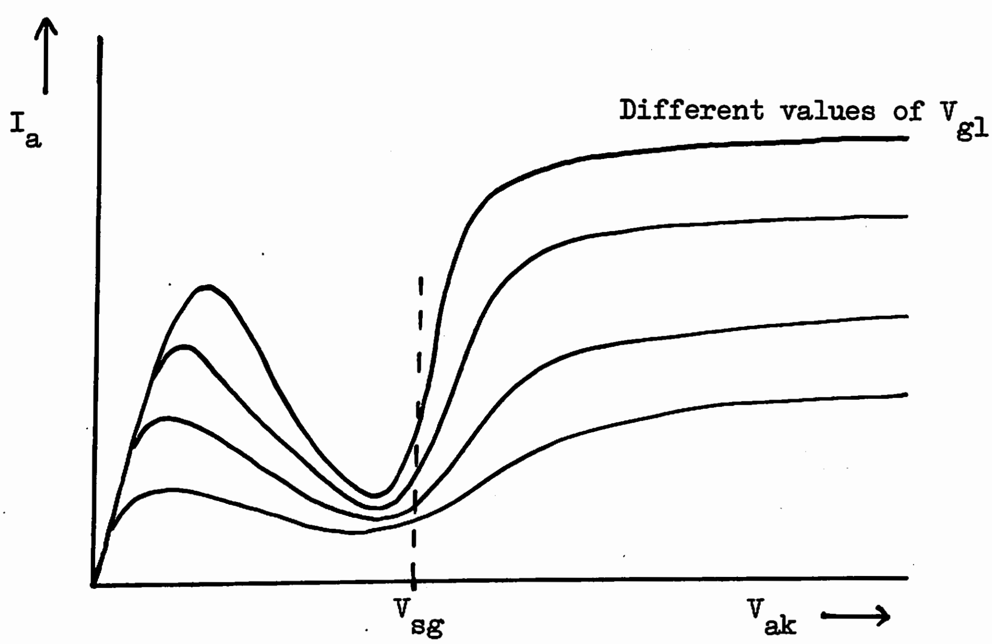


Figure 7: Tetrode Characteristics

In the region of the kink, electrons are accelerated so much by the screen grid that they hit the anode with enough energy to knock others off which then go to the nearest more positive object, i.e. the screen grid. When the anode voltage becomes greater, they return to the anode rather than go to the screen.

With the tetrode (and pentode) valve some current always goes to the screen grid.

By special design features it is possible to eliminate the kink and 'kinkless tetrodes' (eg. the KT 66) were developed for power amplifiers.

6. THE PENTODE VALVE

6.1 Pentode Valve Characteristics

In the pentode a third grid is added to suppress the 'secondary emission' which causes the kink in the tetrode.

This grid is placed between the anode and screen grid and is connected to the cathode. Low velocity electrons leaving the anode are turned back by the 'suppressor grid' while high velocity electrons, accelerated by the screen grid, are not. (See figure 8).

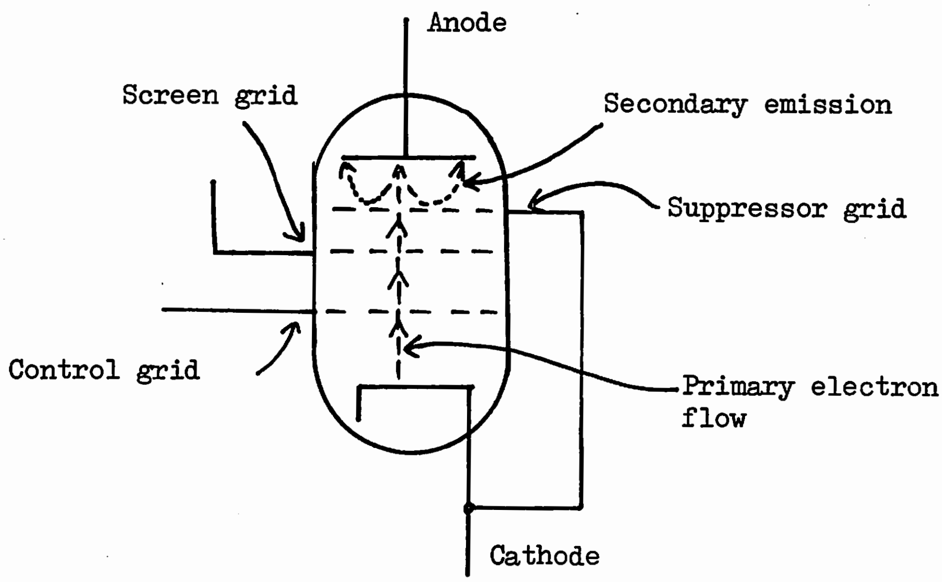


Figure 8: Pentode Valve action

The pentode characteristics have almost flat tops. (See figure 9 and appendix B which show the characteristics of an EF86 pentode).

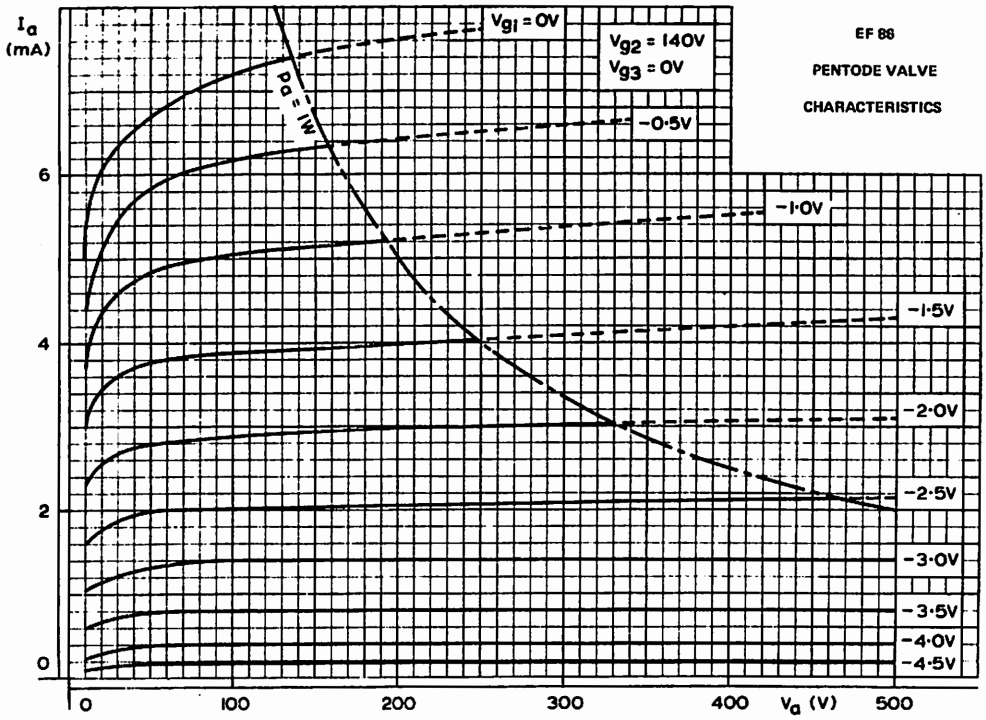


Figure 9: Pentode Valve Characteristics

6.2 Pentode Valve parameters

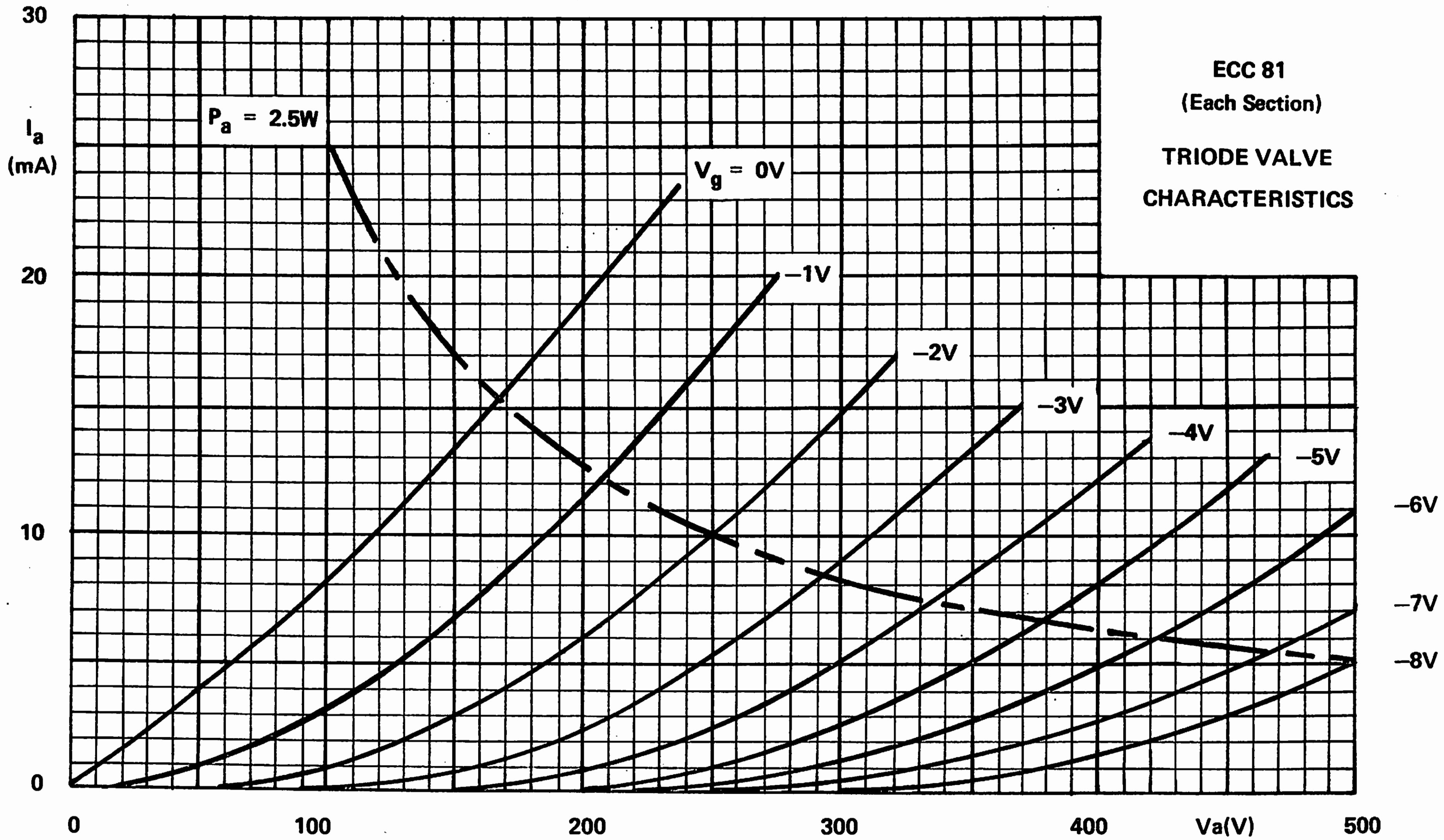
The useful area on the pentode characteristics is the flat part of the curves. As the curves are almost horizontal, r_a is very large (of the order of 1MΩ).

Similarly μ is very large as V_{gk} has a very much bigger effect on I_a than V_{ak}. (μ is typically 1000).

g_m has a similar value to that of a triode (typically about 4mA/V).

R.L. Kendall/VC
16th October 1978

Appendix A



30
20
10
0
I_a (mA)
P_a = 2.5W
V_g = 0V
–1V
–2V
–3V
–4V
–5V
–6V
–7V
–8V
ECC 81
(Each Section)
TRIODE VALVE
CHARACTERISTICS
0
100
200
300
400
Va(V)
500

Appendix B

EF 86

PENTODE VALVE

CHARACTERISTICS