VALVE AMPLIFIERS C Part 1 Course

1. INTRODUCTION

The performance of a valve amplifier can be obtained by adding a loadline to the valve characteristics. Alternatively, if the valve parameters are known, then the gain of the amplifier can be obtained by deriving an equivalent circuit. The loadline method has the advantage that any non linearity can be seen from the characteristics.

2. D.C. LOADLINE

The loadline is the characteristic of the load resistor and has no direct connection with the valve characteristics other than being drawn on the same axis.

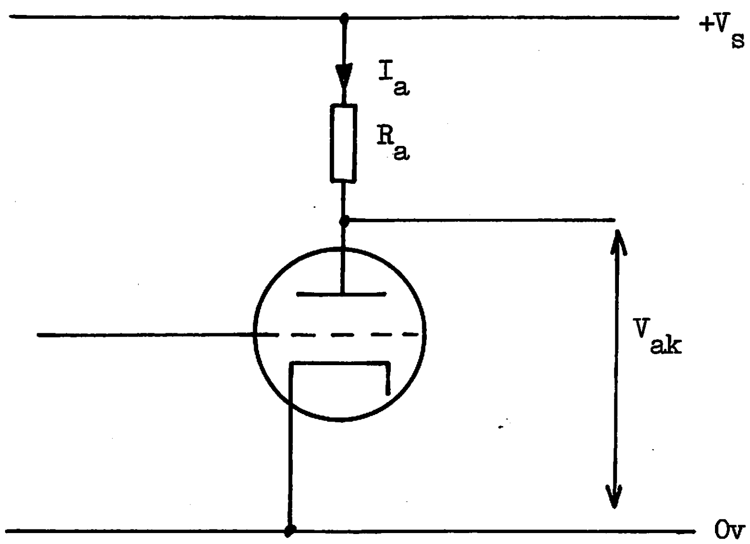

Figure 1: Simple Triode Amplifier Circuit

For the circuit of figure 1, V_{ak} will be given by the supply voltage V_s, less the voltage dropped across R_a.

i.e. $V_{ak} = V_s - I_a \cdot R_a$

This is the equation for a straight line which can be drawn by joining two points. The easiest two points to take are

a) when $V_{ak} = 0$ $V_s = I_a R_a$ or $I_a = \frac{V_s}{R_a}$

and b) when $I_a = 0$, $V_{ak} = V_s$.

(See figure 2)

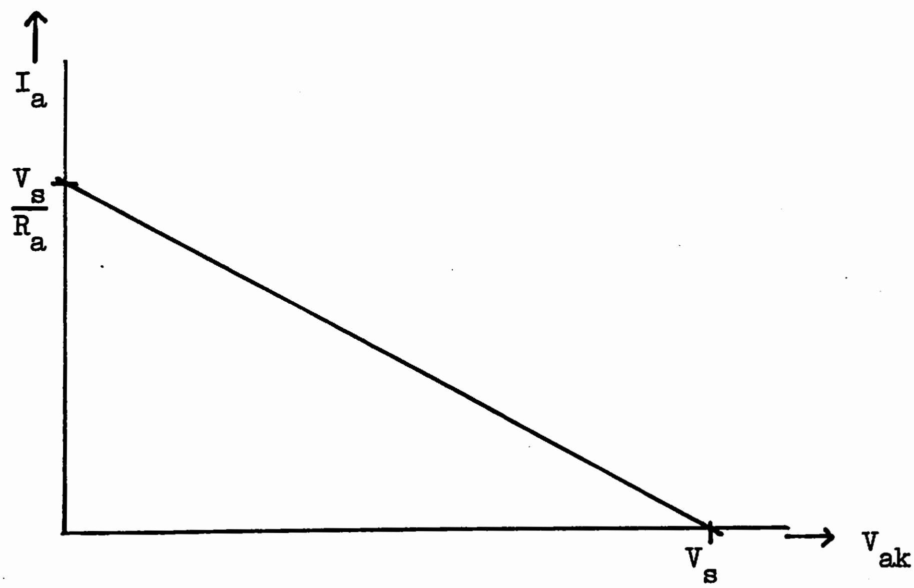

Figure 2: Example of a d.c. loadline

The ends of the loadline correspond to the conditions where the valve is open or short circuit. The d.c. loadline takes account of all the components which pass d.c. between the positive and negative terminals of the supply.

Problem 1

On the characteristics for an ECC 81 triode draw the d.c. loadline for the circuit of figure 3.

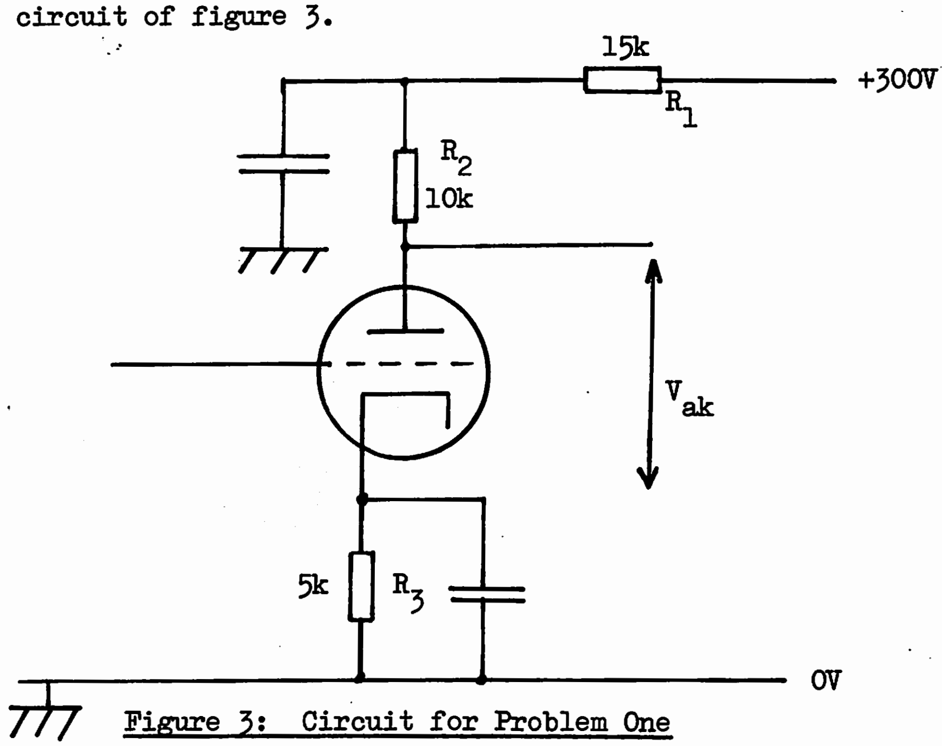

Figure 3: Circuit for Problem One

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3. OPERATING POINT

The operating point is normally selected by the circuit designer to give the least distortion to the signal being amplified. It must be a point on the loadline.

For the loadline drawn in problem one, the operating point for the most linear operating conditions would be near the Vg = -2V characteristic. With less bias the grid lines get further apart while with more grid bias the grid lines get closer together.

If we choose an operating point at Vg = -2V we can obtain the d.c. anode potential and standing (or quiescent) current in the valve from the characteristics, where the load line crosses them.

In this case V_{ak} will be about 174 Volts and I_a will be 4.2 mA.

Problem 2.

What voltage will be measured between anode and ground under these conditions?

4. A.C. LOADLINE

For most applications a valve will operate with an a.c. signal swinging about a d.c. operating point, although the operating point has been established by the d.c. components, a different load might exist for the small signal a.c. conditions.

For the circuit of figure 3, R_1 and R_3 are decoupled by capacitors so that for a.c. signals only R_2 is seen as a load. This means that a different loadline applies for the a.c. conditions. This loadline passes through the d.c. operating point and its slope is determined by the a.c. load resistance.

The two points required to draw the loadling are 'O', the operating point and one other point such as 'A' where $I_a = 0$.

Point A is given by $V_q + I_q \times R_L$ where V_q and I_q are the standing voltage and current on the anode and R_L is the a.c. load.

Problem 3

For the circuit of Problem 1, plot the a.c. loadline for an operating point of $V_{gk} = -2V$.

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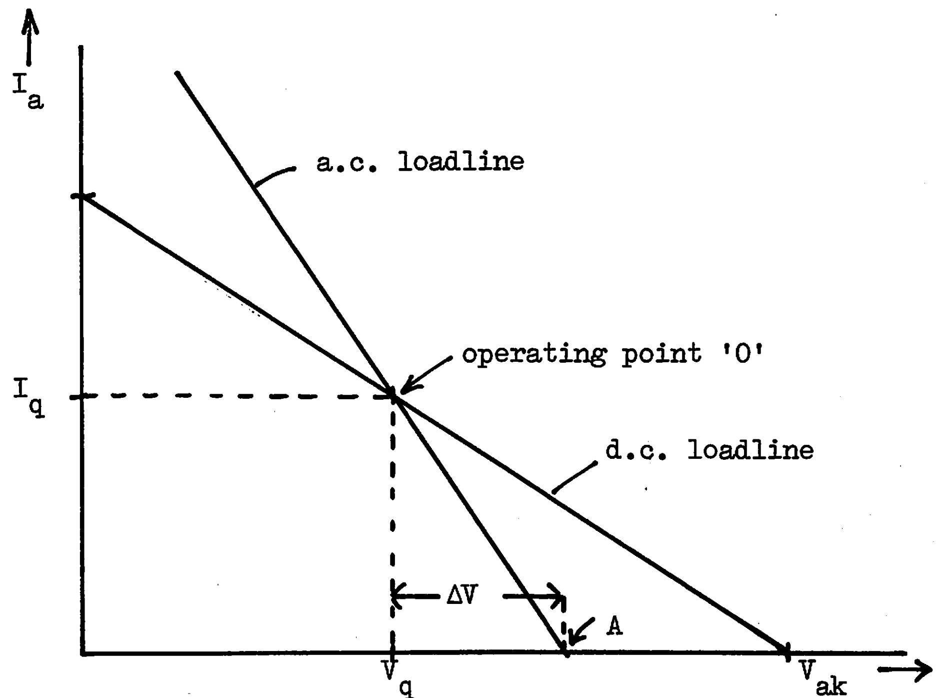

Figure 4: a.c. and d.c. loadlines

5. GAIN FROM A.C. LOADLINE

The valve anode voltage will vary up and down the a.c. loadline when a small a.c. signal is applied. To calculate the gain, mark in the limits of this swing (say ± 1V) on the loadline and drop perpendicular onto the V_{ak} axis. This shows the corresponding swing of V_{ak} (see figure 5).

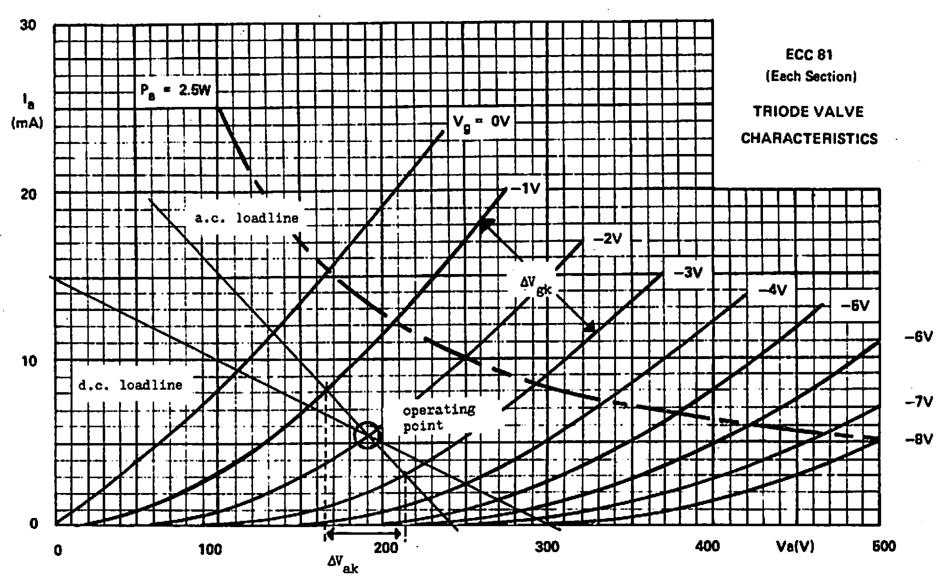

Figure 5: Obtaining gain from a.c. loadline

The gain is then given by the change in V_{ak} divided by the change in V_{gk}, i.e.

$$\text{gain} = \frac{\Delta V_{ak}}{\Delta V_{gk}}$$

One problem which can occur with an a.c. coupled load is that the operating point chosen from the d.c. conditions may not give linear operation under a.c. conditions.

With an a.c. coupled load the d.c. operating point should be chosen to give the best a.c. linearity.

Problem 4.

On EF86 characteristics draw d.c. and a.c. loadlines and calculate the voltage gain of the circuit of figure 6. $V_{gk} = -3V$.

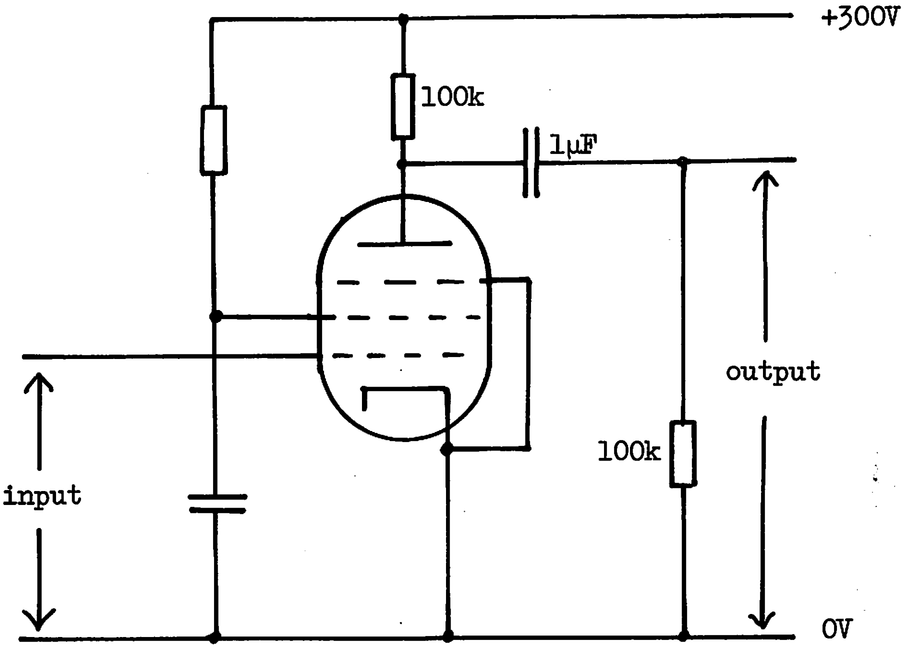

Figure 6: Circuit for problem 4

6. AUTO-BIAS

The necessary grid bias can be obtained by inserting a resistor R_k in the cathode. This is decoupled by C_k.

For the circuit of problem 4, $I_q = 1.4\text{mA}$ and $V_{gk} = -3V$. Thus to obtain 3 volts of bias R_k should be $\frac{V_{gk}}{I_q} = \frac{3}{1.4}\ \text{k}\Omega = 2.14\text{k}\Omega$.

This will affect the d.c. loadline but as R_k is small compared to R_a, it can usually be ignored.

The complete circuit will now be as shown in figure 7.

C_g allows the a.c. signal to be applied to the grid while R_g connects the 'negative end' of R_k to the grid.

From the maintenance point of view we often have to work the opposite way from the designer. We are given a circuit and have to establish the operating point from the circuit components.

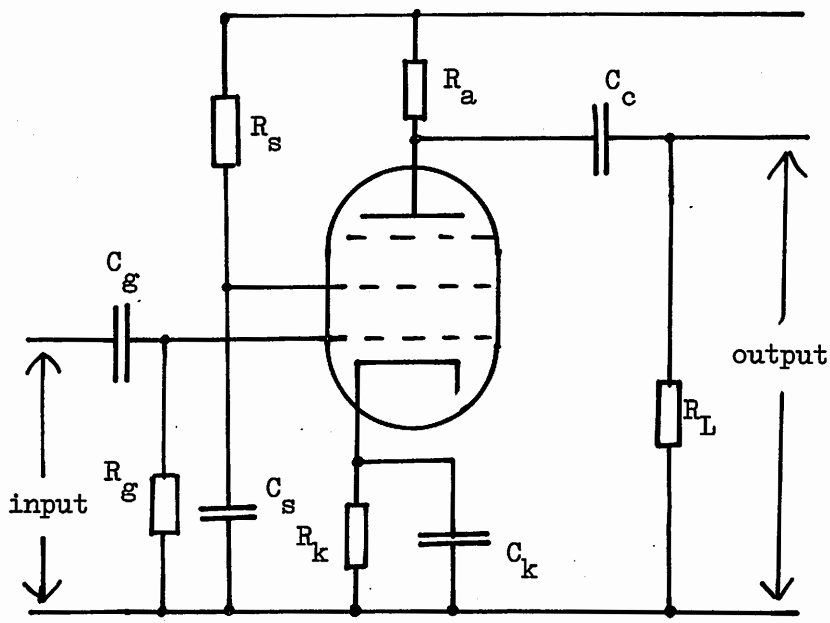

Figure 7: Pentode Amplifier with Auto-Bias

For the circuit of figure 8 we are given R_k but do not know the anode current. To find I_a we can proceed as follows:-

a) Plot the d.c. loadline.

b) Plot a graph of I_a vs V_{gk} using $I_a = \frac{V_{gk}}{R_k}$

N.B. The points should come where the value of I_a is reached on the appropriate V_{gk} line.

The operating point is where these two lines cross (see figure 9).

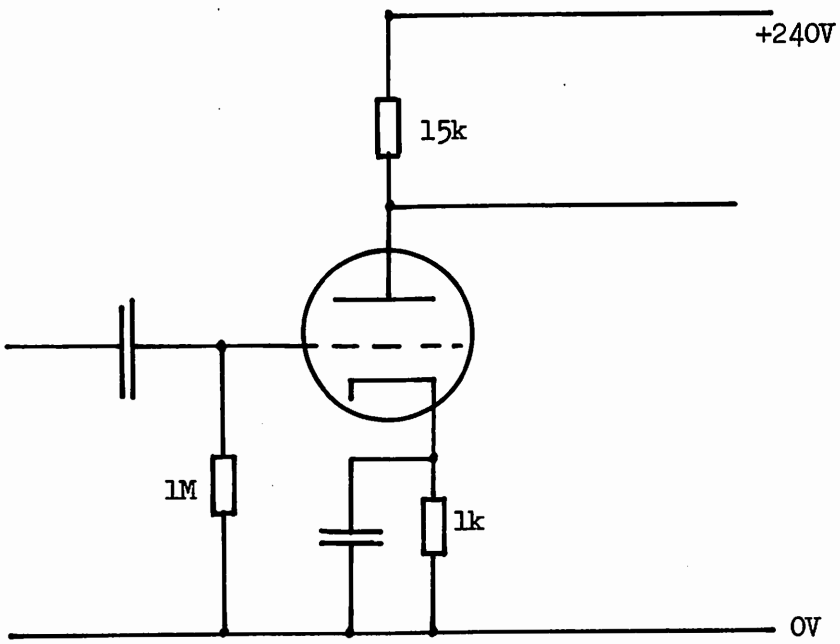

Figure 8: Triode Amplifier with Auto-Bias

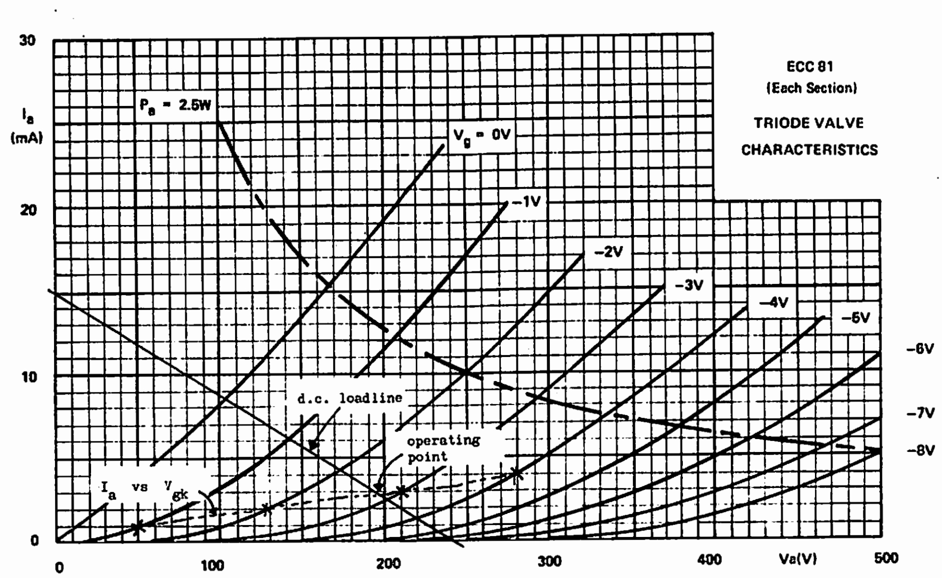

Figure 9: Characteristics for figure 8

7. EQUIVALENT CIRCUIT

Thevenins theorem states that any network of Linear components may be represented by a single generator and impedance in series with it. However, a valve is not a linear device, but if only small signals are used, it will not become nonlinear. It may then be considered as a linear element which can have an equivalent circuit.

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The Thevenin equivalent of a valve will have the form shown in figure 10.

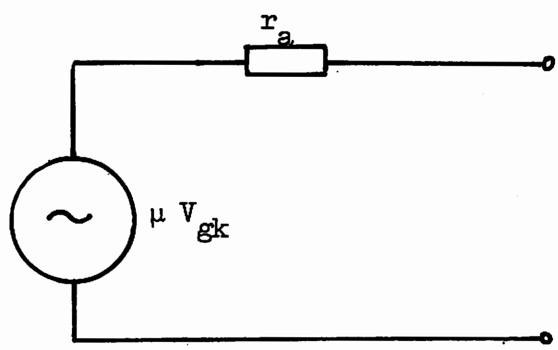

Figure 10: Thevenin equivalent of a valve

An alternative equivalent circuit is the Norton Version. (See figure 11).

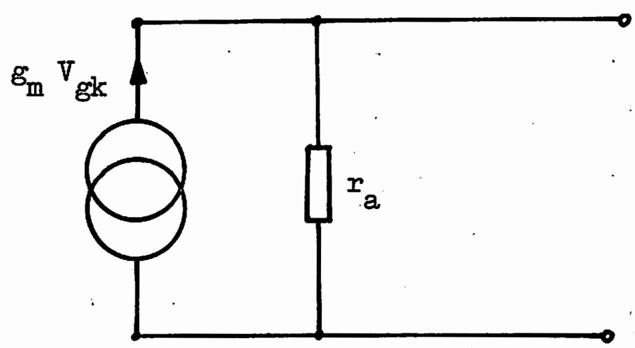

Figure 11: Norton equivalent circuit of a valve

Both these equivalent circuits will only apply for small signal a.c. conditions.

If μ, gm and ra are available (from manufacturers literature) or even only two of the three (as $\mu = gm \times ra$) then we can draw an equivalent circuit. Other circuit components, such as R_a, can then be added to the equivalent circuit to calculate the gain. (See figure 12).

From the equivalent circuit in figure 12b we can derive an expression for the gain:-

$$\text{gain (m)} = \mu \frac{R_a}{(r_a + R_a)}$$

With pentodes, as r_a is very high, the norton equivalent is easier to use. If r_a is very high compared to R_a the equivalent becomes as shown in figure 13.

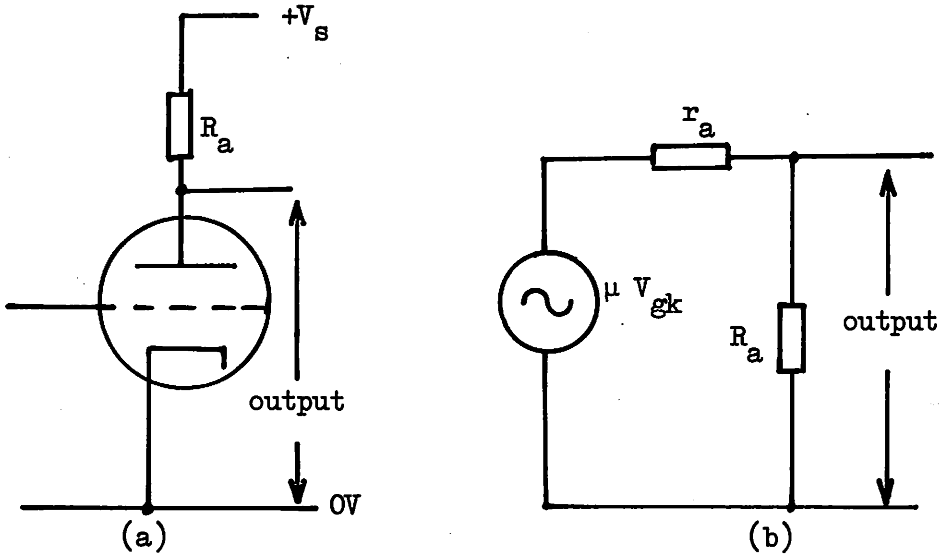

Figure 12: A triode amplifier (a) and its equivalent circuit (b)

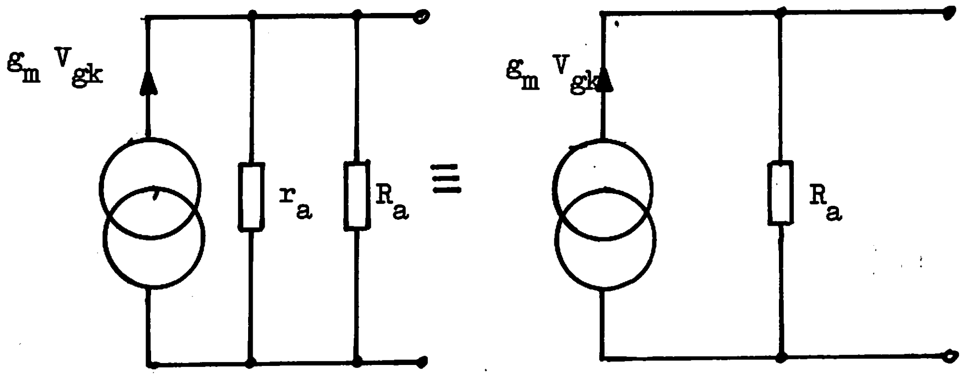

Figure 13: Norton equivalent of a pentode amplifier (a) and its simplified form when $R_a \ll r_a$ (b)

The gain of a pentode then simplifies to

$$m = g_m R_a$$

Problem 5

For the circuit of figure 6 (see problem 4) obtain g_m from the characteristics and calculate the gain from the equivalent circuit.

Problem 6

From the equivalent circuit of problem 5 calculate the 3dB down frequency assuming that the capacitor involved is the 1μf coupling capacitor.

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Answers to Problems

1. Line cuts axis at 10mA and 300V.

2. 195 volts (174 + 4.2 x 5)

3. Line cuts Horizontal axis at V_{ak} = 216 Volts.

4. M = 60

5. $g_m = 1.2$ mA/V $\therefore$ m = 50 x 1.2 = 60

6. $$f_{3dB} = \frac{1}{2\pi\ 10^{-6}\ 200k} = 0.8Hz$$

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