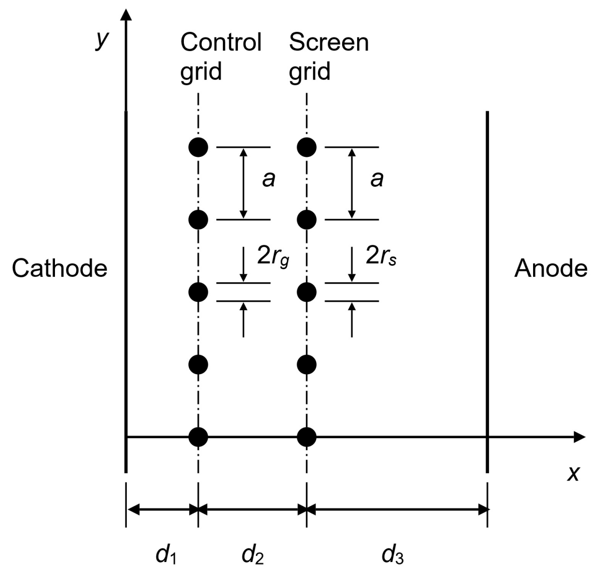
WS 12.3 RS 2058 Tetrode Characteristics

This Mathcad 14 worksheet is designed to accompany the author's book "Microwave and RF Vacuum Electronic Power Sources", Cambridge University Press (2018). The section, equation, and figure numbers refer to the corresponding sections, equations, and figures in the book. Data input fields are highlighted in yellow and output fields are highlighted in green.

This sheet explores the properties and design of the RS 2058 tetrode (see Section 12.3.1) and Siemens (1986). Transmitting Tubes Data Book 1986/87, Siemens AG.



Physical constants

Charge/mass ratio of the electron $\eta := 1.759 \cdot 10^{11} \cdot C \cdot kg^{-1}$

Perveance constant $KK := \frac{4 \cdot \varepsilon_0}{9} \cdot \sqrt{2 \cdot \eta}$ $KK = 2.334\,\mu A \cdot V^{-1.5}$

Plot a graph of the total cathode current to the power 2/3 computed from the published characteristic curves against the grid voltage for screen grid voltages of 700V, 900V and 1100V. This plot shows island formation.

$$V_{g7} := \begin{pmatrix} -200 \\ -80 \\ -40 \\ 5 \\ 50 \\ 90 \\ 130 \\ 190 \end{pmatrix} \quad I_{c7} := \begin{pmatrix} 0.00 \\ 5.00 \\ 10.00 \\ 20.00 \\ 31.80 \\ 44.30 \\ 59.20 \\ 79.00 \end{pmatrix} \qquad V_{g9} := \begin{pmatrix} -230 \\ -115 \\ -70 \\ -25 \\ 20 \\ 65 \\ 130 \\ 230 \end{pmatrix} \quad I_{c9} := \begin{pmatrix} 0.00 \\ 5.00 \\ 10.00 \\ 20.00 \\ 30.70 \\ 42.50 \\ 68.50 \\ 105.00 \end{pmatrix} \qquad V_{g11} := \begin{pmatrix} -270 \\ -125 \\ -90 \\ -50 \\ -10 \\ 30 \\ 95 \\ 170 \end{pmatrix} \quad I_{c11} := \begin{pmatrix} 0.00 \\ 5.00 \\ 10.00 \\ 20.00 \\ 30.00 \\ 41.00 \\ 64.30 \\ 92.00 \end{pmatrix}$$

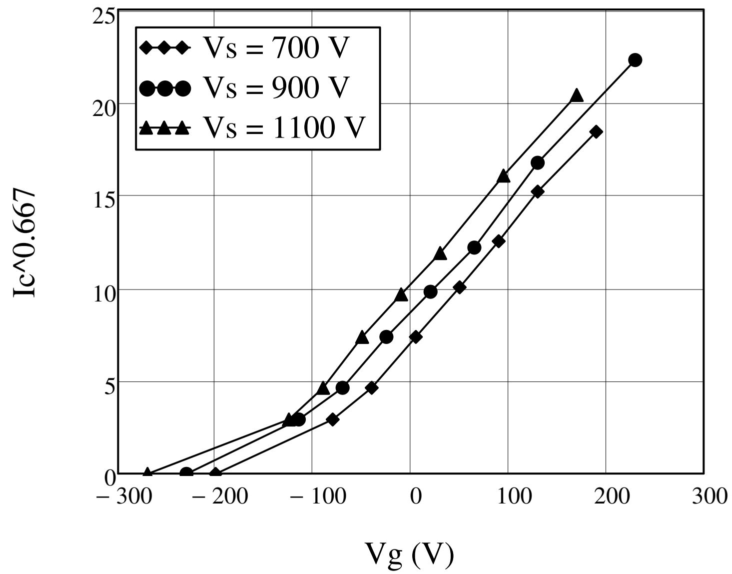


Figure 12.11

Assume that *a* and *r* are the same for both grids. Choose $a := 1 \cdot mm$

The penetration factor for a grid is given by Equation 6.36

$$D(r,d) := \frac{\ln\left(\coth\left(\frac{2\cdot\pi\cdot r}{a}\right)\right)}{\left(\frac{2\cdot\pi\cdot d}{a}\right) - \ln\left(\cosh\left(\frac{2\cdot\pi\cdot r}{a}\right)\right)}$$

where, for the screen grid $D_s = D(r,d_3)$ and for the control grid $D_g = D(r,d_2)$

The distance between the control grid and the anode of the equivalent triode is given by

$$d_e(r,d_1,d_2,d_3) := \frac{d_1 + d_2 + D(r,d_3)\cdot(d_1 + d_2 + d_3)}{1 + D(r,d_3)\cdot\left(1 + \frac{d_3}{d_2}\right)}$$

Equation 6.92

$$D'_g = \frac{D(r,d_2)}{1 + D(r,d_3)\cdot\left(1 + \frac{d_3}{d_2}\right)}$$

Let

$$f1_g(y,d_1) := \frac{\sinh\left(2\cdot\pi\cdot\frac{d_1}{a}\right)}{\cosh\left(2\cdot\pi\cdot\frac{d_1}{a}\right) - \cos\left(\frac{2\cdot\pi\cdot y}{a}\right)}$$

Equation 6.39

Then the penetration factor of the equivalent triode is

$$D_E(y,r,d_1,d_2,d_3) := \frac{d_e(r,d_1,d_2,d_3)\cdot D(r,d_e(r,d_1,d_2,d_3)) + d_1\cdot(1 - f1_g(y,d_1))}{(d_1 + d_e(r,d_1,d_2,d_3))\cdot f1_g(y,d_1) - d_1}$$

Equation 6.94

The penetration factors for the screen grid and the control grid can be found by measurement of the characteristic curves in Figure 12.3. See Equation 6.88 for the definition of D'g. Assume a value for $D_E(y = 0.5\cdot a)$. This value can be adjusted to give self-consistent results.

$Ds := 0.019$ $D'g := 0.15$ $D'E := 0.23$

Find the parameters which make the measured and the calculated penetration factors equal

Note: There are four parameters but only three criteria so that the solution is not unique. However it is found that, if the solutions are re-used as the trial values of the parameters the method converges to a solution which is stable against small changes in the parameters.

Define a function based on the squared difference between the measured and theoretical parameters

$$\mathrm{ferr}(r, d_1, d_2, d_3) := (D(r, d_3) - Ds)^2 + \left[\frac{D(r, d_2)}{1 + D(r, d_3)\cdot\left(1 + \frac{d_3}{d_2}\right)} - D'g\right]^2 + \left[\frac{D_E(0.5\cdot a, r, d_1, d_2, d_3)}{\left[1 + D(r, d_3)\cdot\left(1 + \frac{d_3}{d_2}\right)\right]} - D'E\right]^2$$

Given

$$\begin{pmatrix} r \\ d_1 \\ d_2 \\ d_3 \end{pmatrix} := \begin{pmatrix} 0.061 \\ 0.333 \\ 0.904 \\ 8.432 \end{pmatrix}\cdot mm \qquad X := \mathrm{Minimize}(\mathrm{ferr}, r, d_1, d_2, d_3) \qquad X = \begin{pmatrix} 0.061 \\ 0.333 \\ 0.904 \\ 8.432 \end{pmatrix}\cdot mm$$

Guessed values of the tube dimensions are entered into the yellow matrix. These are replaced repeatedly by the results in the green matrix until convergence is achieved

Check the results by comparison with the input data

$$D_s := D(r, d_3) \qquad D_s = 0.019 \qquad Ds = 0.019$$

$$D'_g := \frac{D(r, d_2)}{1 + D_s\cdot\left(1 + \frac{d_3}{d_2}\right)} \qquad \boxed{\text{Equation 6.88}} \qquad D'_g = 0.15 \qquad D'g = 0.15$$

$$D'_E := \frac{D_E(0.5\cdot a, r, d_1, d_2, d_3)}{\left[1 + D_s\cdot\left(1 + \frac{d_3}{d_2}\right)\right]} \qquad D'_E = 0.23 \qquad D'E = 0.23$$

Note: The value of D'_E is insensitive to the choice of $D'E$

Calculate the cathode current

$$V_e(V_s, V_a) := \frac{V_s + D_s \cdot V_a}{1 + D_s \cdot \left(1 + \frac{d_3}{d_2}\right)}$$

Equation 6.91

Without island formation

$D_g := D(r, d_2)$ $\qquad$ $de := d_e(r, d_1, d_2, d_3)$ $\qquad$ $D_g = 0.179$ $\qquad$ $de = 1.19\,mm$

$$Ic0(V_g, V_s, V_a) := \frac{KK \cdot A_c \cdot \sqrt{1 + D_g} \cdot \left(V_g + D_g \cdot V_e(V_s, V_a)\right)^{1.5}}{\left(d_1 + D_g \cdot de\right)^2}$$

Equation 6.93

With island formation

$$DE(y) := D_E(y, r, d_1, d_2, d_3)$$

$$F_1(V_g, V_s, V_a, y) := \begin{cases} \left[\sqrt{1 + DE(y)} \cdot \frac{\left(V_g + DE(y) \cdot V_e(V_s, V_a)\right)^{1.5}}{\left(d_1 + DE(y) \cdot de\right)^2}\right] & \text{if } \left(V_g + DE(y) \cdot V_e(V_s, V_a)\right) \ge 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Ic(V_g, V_s, V_a) := \frac{KK \cdot A_c}{a} \cdot \int_0^a F_1(V_g, V_s, V_a, y)\, dy$$

Equation 6.96

Adjust the area of the cathode (Ac) so that the current matches that given in the data sheet.
Compare the results with those calculated from the data sheet. $\qquad$ $A_c \equiv 1700 \cdot mm^2$

Plot the computed cathode current to the power 2/3 against the control grid voltage for comparison with the figure above

$V_{g1} := -300, -290 .. 200$ $V_{s1} := 700$ $V_{s2} := 900$ $V_{s3} := 1100$ $V_a := 6000$

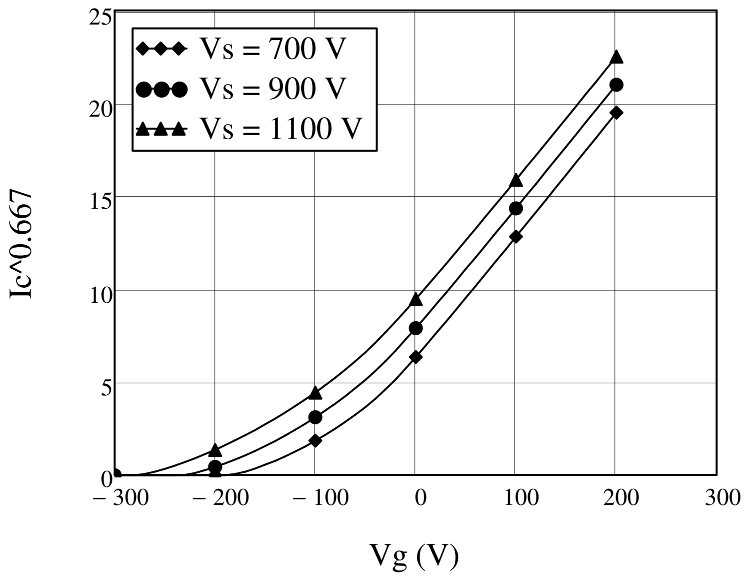


Figure 12.12

Investigate the effect of space charge between the screen grid and the anode

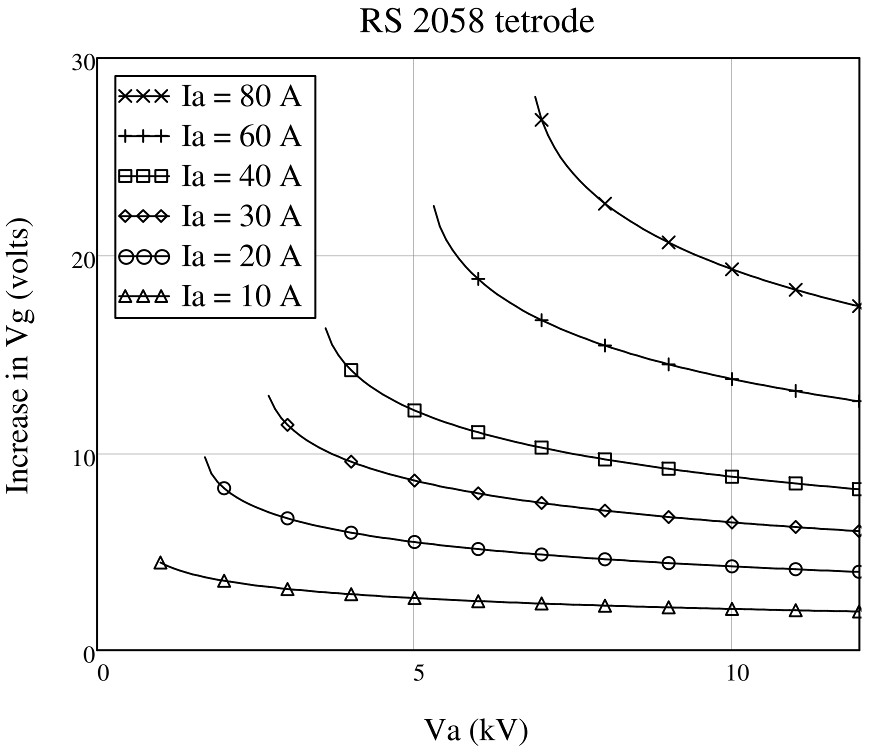
$$X_a(I_a, V_s) := \sqrt{\frac{4 \cdot I_a}{\varepsilon_0 \cdot A_c \cdot \sqrt{2 \cdot \eta} \cdot V_s^{1.5}}} \cdot d_3$$ Equation 6.97

$$W_a(V_s, V_a) := \sqrt{\frac{V_a}{V_s}}$$ Equation 6.98

Find the change in the control grid voltage required to compensate for the space-charge depression. Equation 6.102

$$\Delta V_g(I_a, V_s, V_a) := \left| \begin{array}{l} F1\alpha(I_a, V_s, V_a, \alpha_1) \leftarrow X_a(I_a, V_s) - \frac{4}{3} \cdot \left(W_a(V_s, V_a) - 2 \cdot \alpha_1\right) \cdot \left(W_a(V_s, V_a) + \alpha_1\right)^{\frac{1}{2}} + \frac{4}{3} \cdot (1 - 2 \cdot \alpha_1) \cdot (1 + \alpha_1)^{\frac{1}{2}} \\ F2\alpha(I_a, V_s, V_a, \alpha_1) \leftarrow X_a(I_a, V_s) - \frac{4}{3} \cdot \left(W_a(V_s, V_a) - 2 \cdot \alpha_1\right) \cdot \left(W_a(V_s, V_a) + \alpha_1\right)^{\frac{1}{2}} - \frac{4}{3} \cdot (1 - 2 \cdot \alpha_1) \cdot (1 + \alpha_1)^{\frac{1}{2}} \\ \alpha_1 \leftarrow -0.999 \\ \Delta V_g \leftarrow \left| \begin{array}{ll} \left[D'_g \cdot D_s \cdot \left[V_a - V_s \cdot \left(1 + X_a(I_a, V_s) \cdot \sqrt{1 + \mathrm{root}\left(F1\alpha(I_a, V_s, V_a, \alpha_1), \alpha_1\right)}\right)\right]\right] & \text{if } F1\alpha(I_a, V_s, V_a, -1) \le 0 \\ \left[D'_g \cdot D_s \cdot \left[V_a - V_s \cdot \left(1 - X_a(I_a, V_s) \cdot \sqrt{1 + \mathrm{root}\left(F2\alpha(I_a, V_s, V_a, \alpha_1), \alpha_1\right)}\right)\right]\right] & \text{otherwise} \end{array} \right. \\ \text{return } \Delta V_g \end{array} \right.$$

$V1_a := 1 \cdot kV, 1.1 \cdot kV .. 12 \cdot kV$



Note: This function has the right qualitative behaviour but the curves turn up too sharply as the anode voltage decreases

Calculate the current intercepted by the control grid and hence the anode current

$$\delta\delta := \frac{a}{\frac{a}{\pi\cdot(1+D_g)}\cdot\frac{r}{2\cdot d_1}\cdot\left(1+\ln\left(\frac{4d_1}{r}\right)\right)+2\cdot r}-1$$

Equation 6.62

$$I_g(V_g,V_s,V_a) := \begin{cases}\left(\dfrac{Ic(V_g,V_s,V_a)}{1+\delta\delta\cdot\sqrt{\dfrac{V_e(V_s,V_a)}{V_g}}}\right) & \text{if } V_g \ge 0\\ 0 & \text{otherwise}\end{cases}$$

Equation 6.61

Alternative calculation

$$\mu := \frac{1}{D'_g} \qquad V_{eg\_g}(V_{ag}) := \frac{V_{ag}+\mu}{1+\mu+\frac{d_2}{d_1}} \qquad I_{ag}(V_{ag}) := \frac{a}{2\cdot r}\cdot\sqrt{V_{eg\_g}(V_{ag})}\cdot\left(\frac{2\cdot\ln\left(\frac{a}{2\cdot\pi\cdot r}\right)}{2\cdot\ln\left(\frac{a}{2\cdot\pi\cdot r}\right)+\frac{1}{V_{eg\_g}(V_{ag})}-1}\right)-1$$

Equation 6.66

$$I_g(V_g,V_s,V_a) := \begin{cases}\left(\dfrac{Ic(V_g,V_s,V_a)}{1+I_{ag}\left(\dfrac{V_e(V_s,V_a)}{V_g}\right)}\right) & \text{if } V_g \ge 0\\ 0 & \text{otherwise}\end{cases}$$

Enable evaluation of this line to use it in place of Equation 6.61

Anode current

$$Ia(V_g,V_s,V_a) := Ic(V_g,V_s,V_a) - I_g(V_g,V_s,V_a)$$

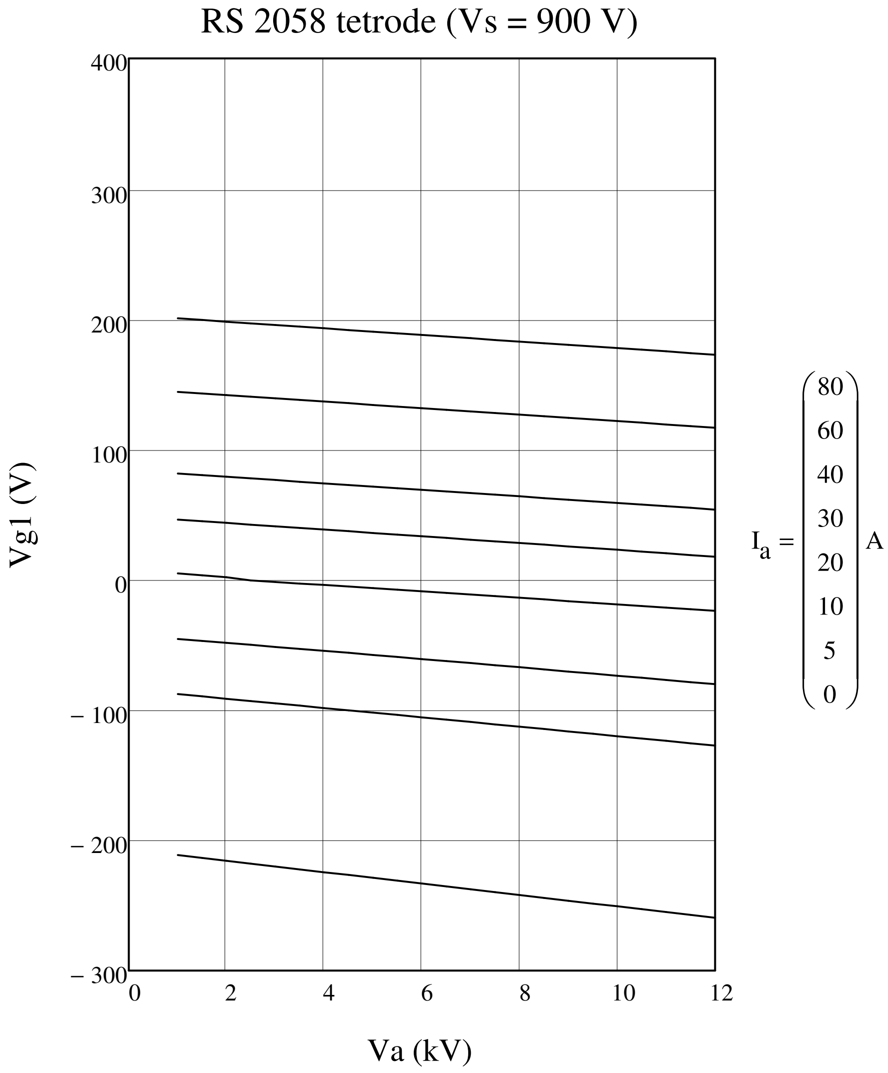
$V_g := 400 \cdot V$ $\quad$ $Vg(I_a, V_s, V_a) := \mathrm{root}(Ia(V_g, V_s, V_a) - I_a, V_g)$ $\quad$ Control grid voltage at constant anode current

$V_{g2} := 100 \cdot V$ $\quad$ $Vg2(Ig, V_s, V_a) := \mathrm{root}(I_g(V_{g2}, V_s, V_a) - Ig, V_{g2})$ $\quad$ Control grid voltage at constant control grid current

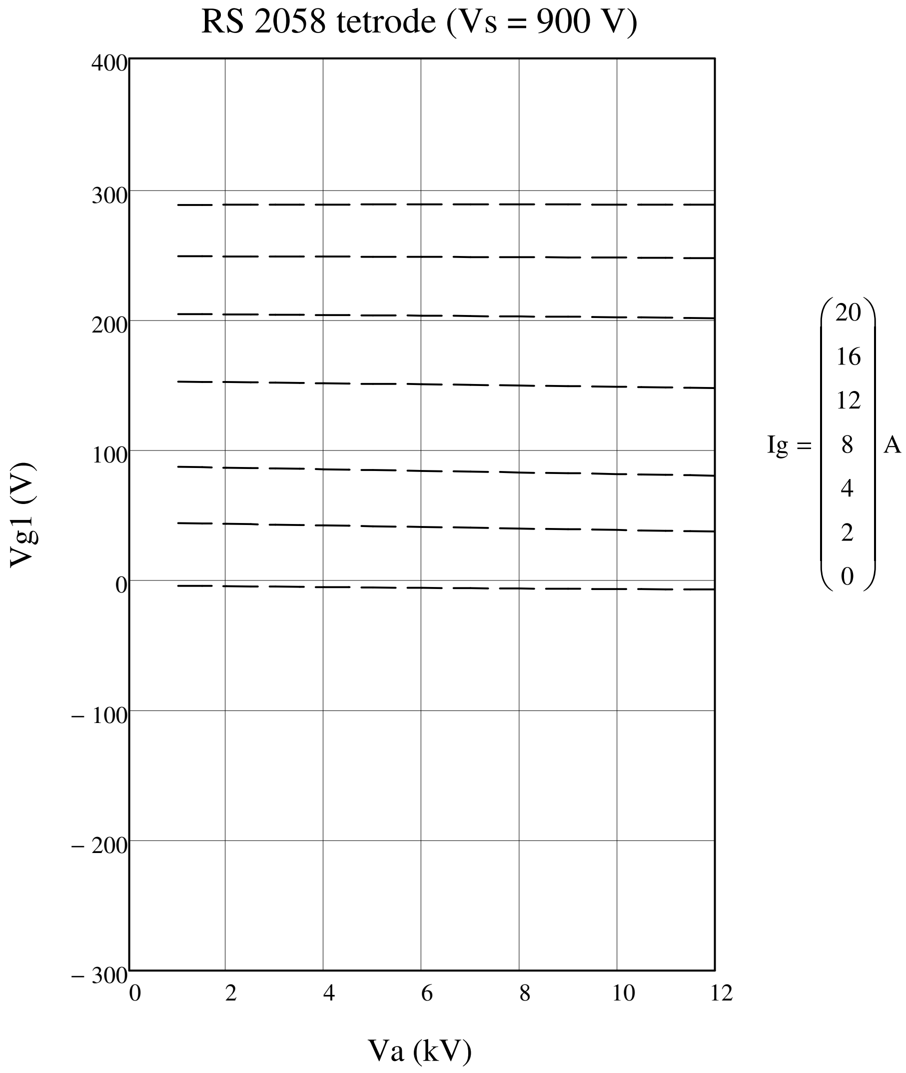
Parameters for plotting the characteristic curves

$V_2 := 1000 \cdot V, 1500 \cdot V .. 12000 \cdot V$ $\quad$ $V_s := 900 \cdot V$ $\quad$ $n := 0..7$ $\quad$ $nn := 0..6$

$$I_a := \begin{pmatrix} 80 \\ 60 \\ 40 \\ 30 \\ 20 \\ 10 \\ 5 \\ 0 \end{pmatrix} \cdot A \qquad Ig := \begin{pmatrix} 20 \\ 16 \\ 12 \\ 8 \\ 4 \\ 2 \\ 0 \end{pmatrix} \cdot A$$



RS 2058 tetrode (Vs = 900 V)
Vg1 (V)
Va (kV)
400
300
200
100
0
– 100
– 200
– 300
0
2
4
6
8
10
12
$I_a = \begin{pmatrix} 80 \\ 60 \\ 40 \\ 30 \\ 20 \\ 10 \\ 5 \\ 0 \end{pmatrix} A$



RS 2058 tetrode (Vs = 900 V)
Vg1 (V)
Va (kV)
400
300
200
100
0
– 100
– 200
– 300
0
2
4
6
8
10
12
$Ig = \begin{pmatrix} 20 \\ 16 \\ 12 \\ 8 \\ 4 \\ 2 \\ 0 \end{pmatrix} A$

Figure 12.13

Calculation of possible tube dimensions

$f := 220 \cdot MHz$ $\quad Vg1 := 350 \cdot V$ $\quad d_1 = 0.333 \cdot mm$ $\quad u_0 := \sqrt{2 \cdot \eta \cdot Vg1}$ $\quad \beta_e := \dfrac{2 \cdot \pi \cdot f}{u_0}$

Choose the normalised distance between the cathode and the control grid (see Section 5.7)

$\beta ed1 := 0.1$ $\quad \sqrt{1 + (2 \cdot \beta ed1)^2} = 1.02$ The scale factor is $scale := \dfrac{\beta ed1}{\beta_e \cdot d_1}$ $\quad scale = 2.41$

The tube dimensions are

Grid spacing		$a \cdot scale = 2.4 \cdot mm$
Grid wire radius		$r \cdot scale = 0.147 \cdot mm$
Cathode-control grid spacing		$d_1 \cdot scale = 0.8 \cdot mm$
Control grid-screen grid spacing		$d_2 \cdot scale = 2.2 \cdot mm$
Screen grid-anode spacing		$d_3 \cdot scale = 20.3 \cdot mm$
Cathode length (wavelength/16)	$L_c := \dfrac{c}{16 \cdot f}$	$L_c = 85\,mm$
Cathode diameter	$d_c := \dfrac{A_c \cdot scale^2}{\pi \cdot L_c}$	$d_c = 37\,mm$
Screen grid diameter	$d_s := d_c + 2\left(d_1 + d_2\right) \cdot scale$	$d_s = 43\,mm$
Anode inner diameter	$d_a := d_s + 2d_3 \cdot scale$	$d_a = 84\,mm$
Maximum cathode current density	$J_{max} := \dfrac{100 \cdot A}{A_c \cdot scale^2}$	$J_{max} = 1.0\,A \cdot cm^{-2}$