WS 12.4 Tetrode design calculations

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 worksheet investigates the design of a high power tetrode having performance similar to the RS 2074 (TH 558) (see Section 12.4).

Statement of requirements

RF output power $P_1 := 600 \cdot kW$ Frequency $f := 110 \cdot MHz$

Physical constants

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

Perveance constant $KK := \frac{4\varepsilon_0}{9} \cdot \sqrt{2 \cdot \eta}$

1. Determine the DC operating point

Estimated efficiency for class B operation $\eta_e := 0.7$

DC input power required $P_0 := \frac{P_1}{\eta_e}$ $P_0 = 857\,\text{kW}$

Choose the DC anode voltage $V_0 := 15 \cdot \text{kV}$

DC anode current $I_0 := \frac{P_0}{V_0}$ $I_0 = 57\,\text{A}$

Peak anode current $I_{a\_pk} := \frac{I_0}{0.28}$ from Figure 12.5(b) $I_{a\_pk} = 204\,\text{A}$

Assume that the grid currents total 20% of the cathode current at the peak current

Peak cathode current $I_{c\_pk} := \frac{I_{a\_pk}}{0.8}$ $I_{c\_pk} = 255\,\text{A}$

2. Determine the RF operating conditions

Choose the screen grid voltage

$V_s := 0.1 \cdot V_0$

$V_s = 1.5\,\text{kV}$

Control grid penetration factor

$D_g := 0.2$

Approximate control grid voltage at cut-off

$V_{g\_0} := -D_g \cdot V_s$

$V_{g\_0} = -300\,\text{V}$

Choose peak control grid voltage

$V_{g\_pk} := 100 \cdot \text{V}$

RF grid voltage for class B operation

$V_{g1} := V_{g\_pk} - V_{g\_0}$

$V_{g1} = 400\,\text{V}$

Choose minimum anode voltage

$V_{a\_min} := 0.15 \cdot V_0$

$V_{a\_min} = 2.25\,\text{kV}$

RF anode voltage

$V_1 := V_0 - V_{a\_min}$

$V_1 = 12.75\,\text{kV}$

RF anode current

$I_1 := \frac{I_{a\_pk}}{2}$

$I_1 = 102\,\text{A}$

CHECK RF output power

$\frac{1}{2} \cdot V_1 \cdot I_1 = 651\,\text{kW}$

Note: this can be computed more accurately after the characteristic curves have been calculated (see Section 12.5)

3. Determine the dimensions of the tube

Choose the normalised cathode-grid spacing

$\beta ed1 := 0.05$

$\sqrt{1 + (2 \cdot \beta ed1)^2} = 1.005$

Find the cathode-control grid spacing

$\beta_e := \frac{2 \cdot \pi \cdot f}{\sqrt{2 \cdot \eta \cdot V_{g1}}}$

$d_1 := \frac{\beta ed1}{\beta_e}$

$d_1 = 0.86\,mm$

Choose grid spacing to avoid island formation

$a := d_1$

$a = 0.86\,mm$

Choose spacing between the grids

$d_2 := d_1$

$d_2 = 0.86\,mm$

Find the control grid wire radius from D_g

$$Dg(r_g) := \frac{\ln\left(\coth\left(\frac{2 \cdot \pi \cdot r_g}{a}\right)\right)}{\left(\frac{2 \cdot \pi \cdot d_2}{a}\right) - \ln\left(\cosh\left(\frac{2 \cdot \pi \cdot r_g}{a}\right)\right)}$$

Equation 6.36

$rg := 0.01 \cdot mm$

$r_{g1} := root(Dg(rg) - D_g, rg)$

$r_{g1} = 0.040\,mm$

CHECK

$Dg(r_{g1}) = 0.2$

Choose the screen grid wire radius

$r_{g2} := 1.3 \cdot r_{g1}$

$r_{g2} = 0.052 \cdot mm$

Choose the screen grid-anode spacing

$d_3 := 8 \cdot d_1$

Find the screen grid penetration factor

$$D_s := \frac{\ln\left(\coth\left(\frac{2 \cdot \pi \cdot r_{g2}}{a}\right)\right)}{\left(\frac{2 \cdot \pi \cdot d_3}{a}\right) - \ln\left(\cosh\left(\frac{2 \cdot \pi \cdot r_{g2}}{a}\right)\right)}$$

$D_s = 0.02$

4. Compute the characteristic curves for the tube

Grid-anode spacing of the equivalent triode

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

Equation 6.92

$d_e = 1.60\,\text{mm}$

Anode voltage of the equivalent triode

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

Equation 6.91

Cathode current density

$$J_c(V_g, V_s, V_a) := \frac{KK \cdot \sqrt{1 + D_g} \cdot (V_g + D_g \cdot V_e(V_s, V_a))^{1.5}}{(d_1 + D_g \cdot d_e)^2}$$

Equation 6.93

Peak cathode current density

$J_c(V_{g\_pk}, V_s, 0.15V_0) = 1.27 \cdot A \cdot cm^{-2}$

Area of the cathode

$$A_c := \frac{I_{c\_pk}}{J_c(V_{g\_pk}, V_s, 0.15V_0)}$$

$A_c = 201\,\text{cm}^2$

Cathode current

$$I_c(V_g, V_s, V_a) := A_c \cdot J_c(V_g, V_s, V_a)$$

Choose the length of the anode

$$\lambda := \frac{c}{f} \qquad L_a := \frac{\lambda}{16}$$

$L_a = 170\,\text{mm}$

Cathode diameter

$$d_c := \frac{A_c}{\pi \cdot L_a}$$

$d_c = 38\,\text{mm}$

Anode inner diameter

$$d_a := d_c + 2 \cdot (d_1 + d_2 + d_3)$$

$d_a = 55\,\text{mm}$

Primary current division factor

$$\delta\delta := \frac{a}{\frac{a}{\pi\cdot\left(1+D_g\right)}\cdot\frac{r_{g1}}{2\cdot d_1}\cdot\ln\left(\frac{4\cdot e\cdot d_1}{r_{g1}}\right)+2\cdot r_{g1}} - 1$$

Equation 6.62

Grid current / anode current

$$GF\left(V_g,V_s,V_a\right) := \frac{1}{\delta\delta}\cdot\sqrt{\frac{V_g}{V_e\left(V_s,V_a\right)}}$$

Equation 6.61

Grid current

$$I_g\left(V_g,V_s,V_a\right) := \frac{GF\left(V_g,V_s,V_a\right)}{1+GF\left(V_g,V_s,V_a\right)}\cdot I_c\left(V_g,V_s,V_a\right)$$

Anode current

$$I_a\left(V_g,V_s,V_a\right) := I_c\left(V_g,V_s,V_a\right) - I_g\left(V_g,V_s,V_a\right)$$

Find grid voltage for constant anode current

$$V_g := 0\cdot V \qquad V1_g\left(Ia,V_s,V_a\right) := root\left(I_a\left(V_g,V_s,V_a\right) - Ia, V_g, -400\cdot V, 400\cdot V\right)$$

Anode dissipation

$$P_a := \left(1-\eta_e\right)\cdot P_0$$

$P_a = 257\,kW$

Anode power density

$$W_a := \frac{P_a}{\pi\cdot d_a\cdot L_a}$$

$W_a = 877\,W\cdot cm^{-2}$

Summary of the tube dimensions

$a = 0.86\cdot mm$	$r_{g1} = 0.040\cdot mm$	$r_{g2} = 0.052\cdot mm$
$d_1 = 0.86\cdot mm$	$d_2 = 0.86\cdot mm$	$d_3 = 6.9\cdot mm$
$d_c = 38\,mm$	$L_a = 170\,mm$	$d_a = 55\,mm$

$V1_a := 1.5 \cdot kV, 1.6 \cdot kV .. 15 \cdot kV$