Appendix

Klystron: Gun (1)

- Cathode typical:

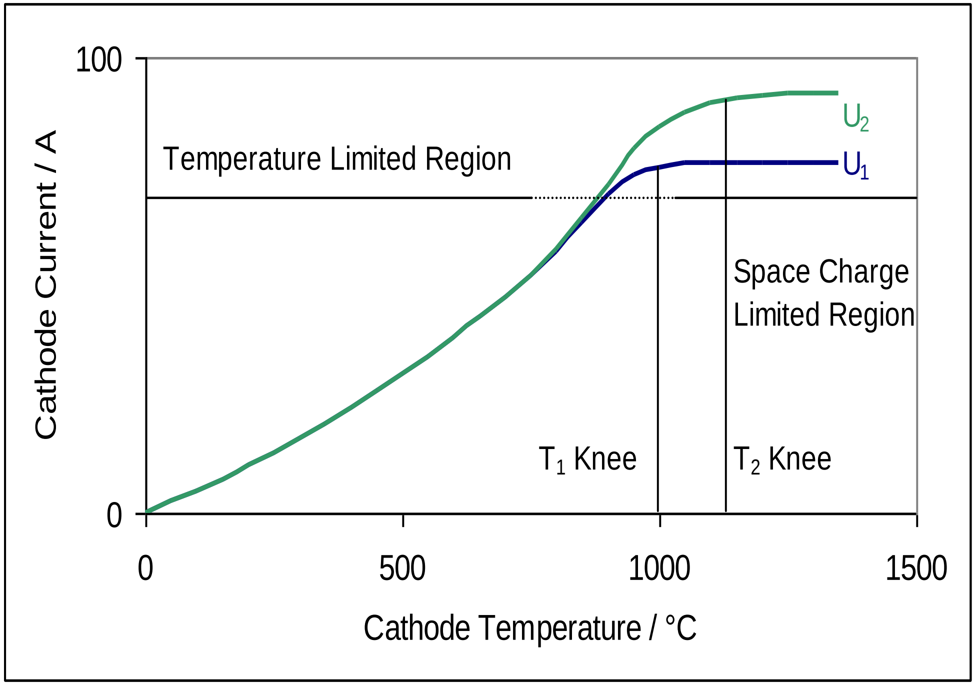
  A) M-Type: Tungsten-Matrix impregnated with Ba and coated with Os/Ru

  B) Oxide (BaO, CaO or SO)

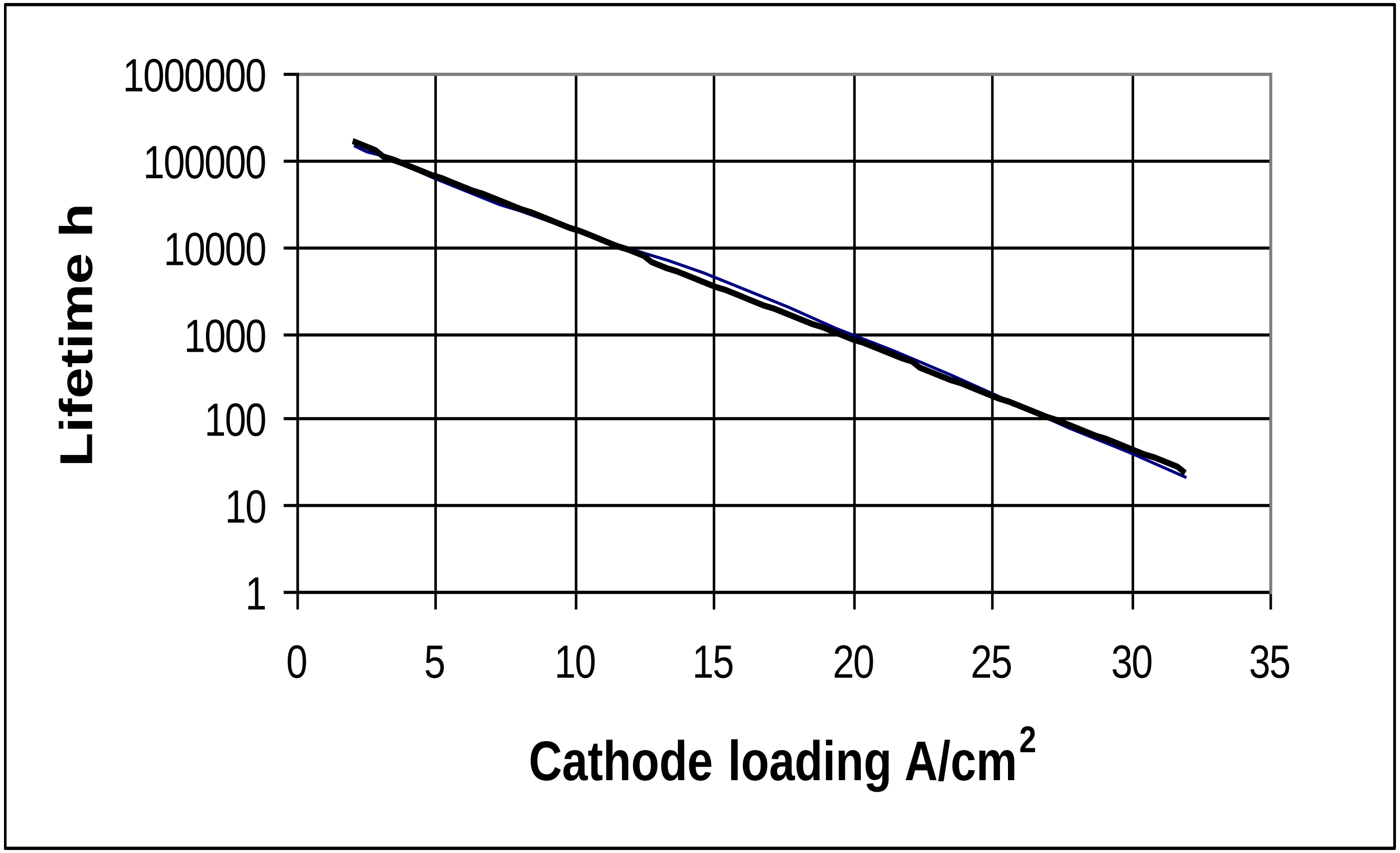
- Cathode is operated in the space charge limited region (Child-Langmuir Theory)

  $j=(4/9)\mathbf{e}_0[(2e)/m]^{1/2}U^{3/2}/d$

- Integration gives: $I=pU^{3/2}$



Klystron: Gun (2)



For higher cathode loading it is required to operate at higher cathode temperature => the cathode lifetime decreases.

Klystron: Beam Focussing

- Confined flow: The cathode is in the magnetic field of a solenoid (common in travelling wave tubes).

- Brillouin focussing: No magnetic field lines are threading through the cathode. The beam is entering the magnetic field of a (electromagnetic) solenoid around the drift tube section.

  B is B=1.2 - 2 x B_B (typ ~1000G)

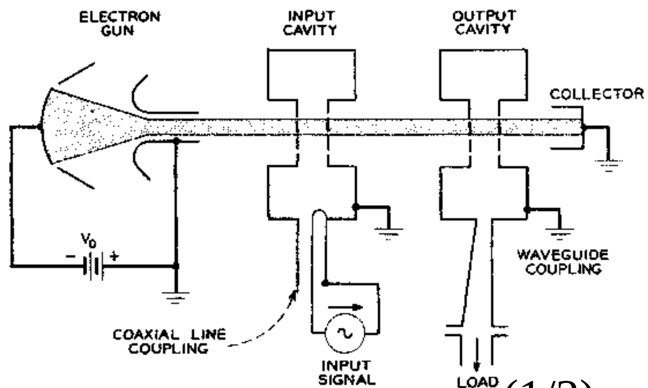
  with B_B Brillouinfield

  with b beam radius, u_e beam velocity, I beam current

- Focussing can also be done with permanet magnets: Periodic Permanent Magnet focussing (PPM) e.g. pulsed high power X-Band klystrons (SLAC, KEK).

$$B_B = \sqrt{(2I\, m_0)/(\varepsilon_0 \pi b^2 u_e e)}$$

Klystron: Ballistic Theory (1)
Treatment of individual electrons without interaction



Inititial electron energy: $(1/2)mu_0^2=eV_0$

Electron Energy gain in the input cavity: $(1/2)mu^2-(1/2)\ mu_0^2=eV_1 \sin wt$

$$u=u_0(1+(mV_1/V_0)\sin wt)^{1/2}$$

Assume $V_1<<V_0$: $u=u_0(1+(mV_1/2V_0)\sin wt)$

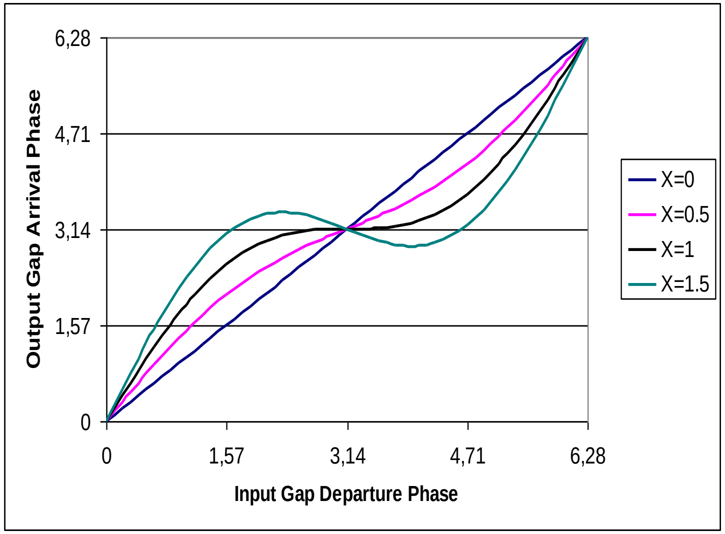
The arrival time t_2 in the second cavity depends on the departure time t_1 in the first cavity with the assumption of an infinite thin gap:

$$t_2=t_1+l/u=t_1+l/u_0(1+(mV_1/2V_0)\sin wt_1)=t_1+l/u_0-(lmV_1/2u_0V_0)\sin wt_1)$$

or $wt_2=wt_1+q_0-X\sin wt_1$ with $q_0=l/u_0$ and $X=q_0mV_1/2V_0$ called bunching parameter

Klystron: Ballistic Theory (2)

Because of charge conservation: Charge in the input cavity between time t_1 and t_1+dt_1 equals the charge in the output cavity between time t_2 and t_2+dt_2

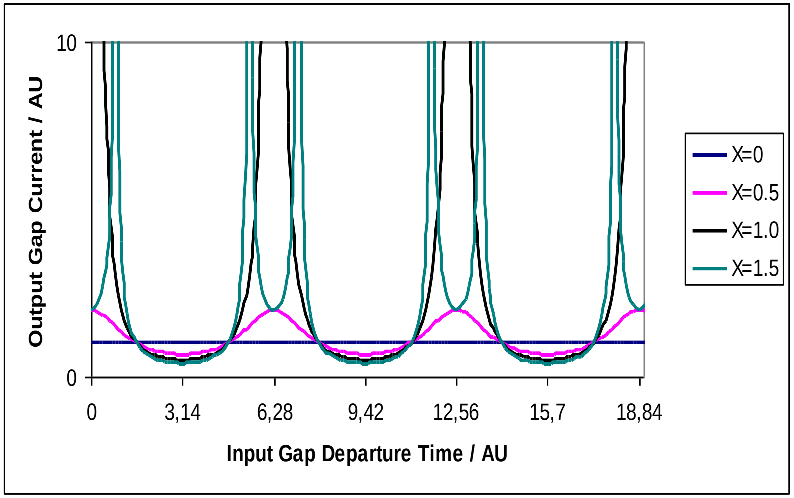


$I_1 dt_1 = I_2 dt_2$

With $dt_2/dt_1 = 1 - X\cos wt_1$ and $I_2 = I_1/(dt_2/dt_1)$ one gets

$I_2 = I_1 1 /(1 - X\cos wt_1)$

$I_2 = I_1 ABS(1 /(1 - X\cos wt_1))$



Klystron: Ballistic Theory (3)

Fourier transformation of the current in the output gap I_2

$$I_2 = I_0 + \sum_{n=1}^{\infty} [\, a_n \cos n(\omega t_2 - \theta_0) + b_n \sin(\omega t_2 - \theta_0)]$$

$$a_n = (1/\pi) \int_{\theta_0-\pi}^{\theta_0+\pi} I_2 \cos n(\omega t_2 - \theta_0) d(\omega t_2) \qquad b_n = (1/\pi) \int_{\theta_0-\pi}^{\theta_0+\pi} I_2 \sin n(\omega t_2 - \theta_0) d(\omega t_2)$$

$$a_n = (I_0/\pi) \int_{-\pi}^{\pi} \cos n(\omega t_1 - X \sin \omega t_1) d(\omega t_1)$$

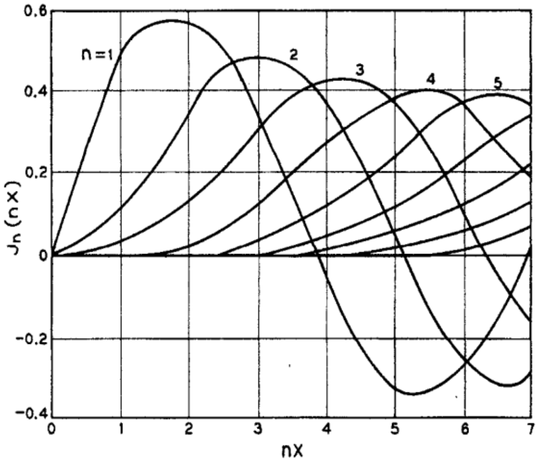
$$b_n = (I_0/\pi) \int_{-\pi}^{\pi} \sin n(\omega t_1 - X \sin \omega t_1) d(\omega t_1) = 0$$

$a_n = 2 I_0 J_n(nX)$ with J_n Besselfunction of the n- th order

Klystron: Ballistic Theory (4)

$$I_2 = I_0 + 2 I_0 \sum_1^{\infty} J_n(nX)\cos n(\omega t_1 - \theta_0)$$

$$I_\omega = 2 I_0 J_1(X)\cos(\omega t - \theta_0)$$



Bessel functions of various orders. The maximum value of J_1 occurs at $X = 1.84$ and is equal to 0.582.

Maximum Output Power:

$$P_\omega = \overline{I_\omega V_\omega} = 2\times 0.58 (I_0/\sqrt{2})(V_0/\sqrt{2}) = 0.58\, P_{Beam}$$

Klystron: Space Charge Waves

- Space charge forces counteract the bunching
- Any perturbation in an electron beam excites an oscillation with the plasma frequency
- Therefore we have 2 waves with the Phase constants
- And therefore
- The group velocity is
- The density modulations appear at a distance of

$$\Omega = \sqrt{\left((e/m_0)(\rho_0/\varepsilon_0)\right)}$$

$$\beta_{e1} = \beta_e(1+\Omega/\omega)$$

$$\beta_{e2} = \beta_e(1-\Omega/\omega)$$

$$\beta_e = \omega/u_e \qquad u_{e2} = u_e/(1-\Omega/\omega)$$

$$u_{e1} = u_e/(1+\Omega/\omega)$$

$$u_g = d\omega/d\,\beta_e = u_e$$

$$\lambda_p = 2\pi\, u_e/\Omega$$

This means that the driftspace or the distance between cavities is determined by the plasma frequency (klystron current) and the electron velocity (klystron voltage) and is given by $\lambda_p/4$

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Klystron: Coupling (1)

- Up to now we have neglected the transit time t in the cavity gap
- The transit angle is: f=wt
- The coupling factor is: K_1=(sin(f/2))/(f/2)
  e.g. K_1=1 max if f=0 (infinite thin gap)
- In addition there is the transversal coupling factor
  $K_t=J_0(b_e r)/J_0(b_e b)$ with b=beam radius and r=tunnel radius and J_0 modified Besselfunction
- The total coupling factor is $K=K_1K_t$ and determines the RF voltage in the cavity gap generated by the RF current
- A typical number is K ~0.85 at ~1GHz