4.3 Reflex Klystron Oscillator

Module:4 Microwave Sources

Course: BECE305L – Antenna and Microwave Engineering

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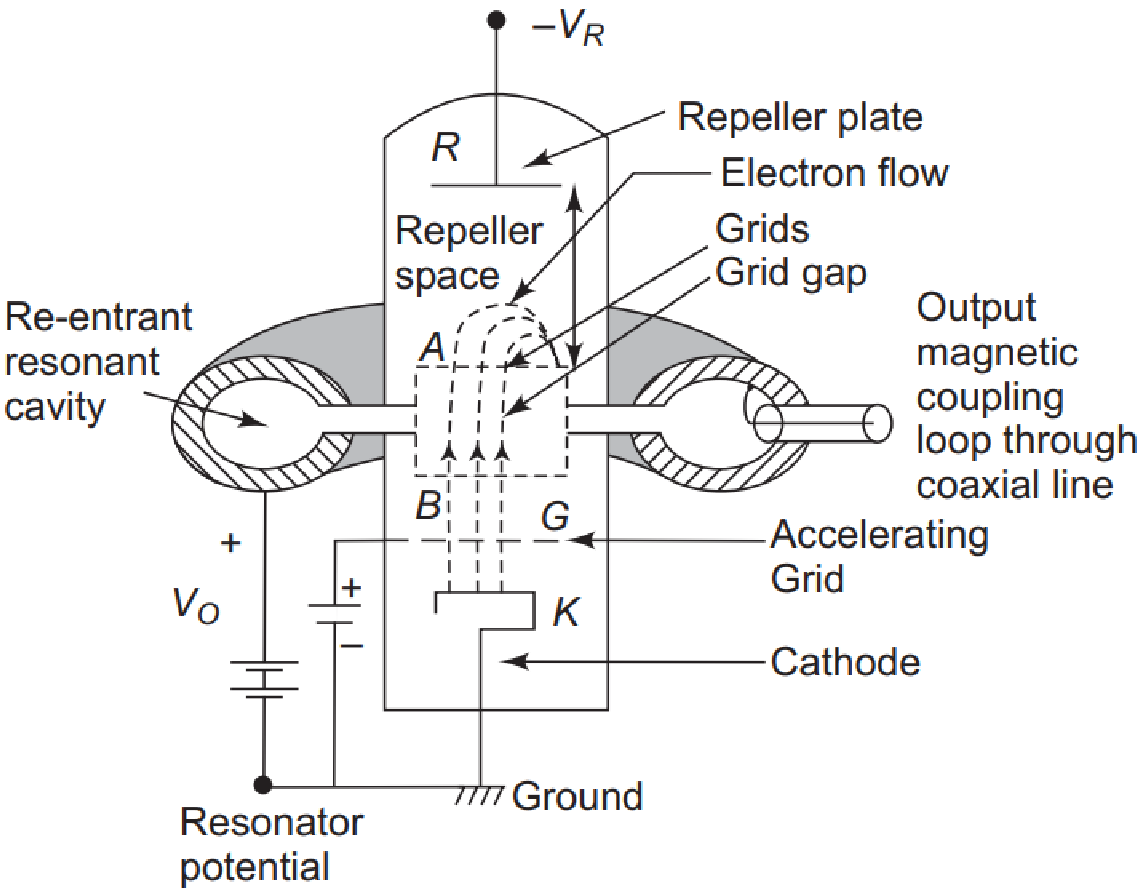
Module:4 Microwave Sources 5 hours

- Microwave frequencies and applications, Microwave Tubes: TWT, Klystron amplifier, Reflex, Klystron & Magnetron. Semiconductor Devices: Gunn diode, Tunnel diode, IMPATT – TRAPATT - BARITT diodes, PIN Diode.

6.1 Reflex Klystron Oscillator

- Low power microwave oscillator (source)
- Single re-entrant microwave cavity as a resonator.



Das - Microwave Engineering (2014, Mc Graw Hill India)

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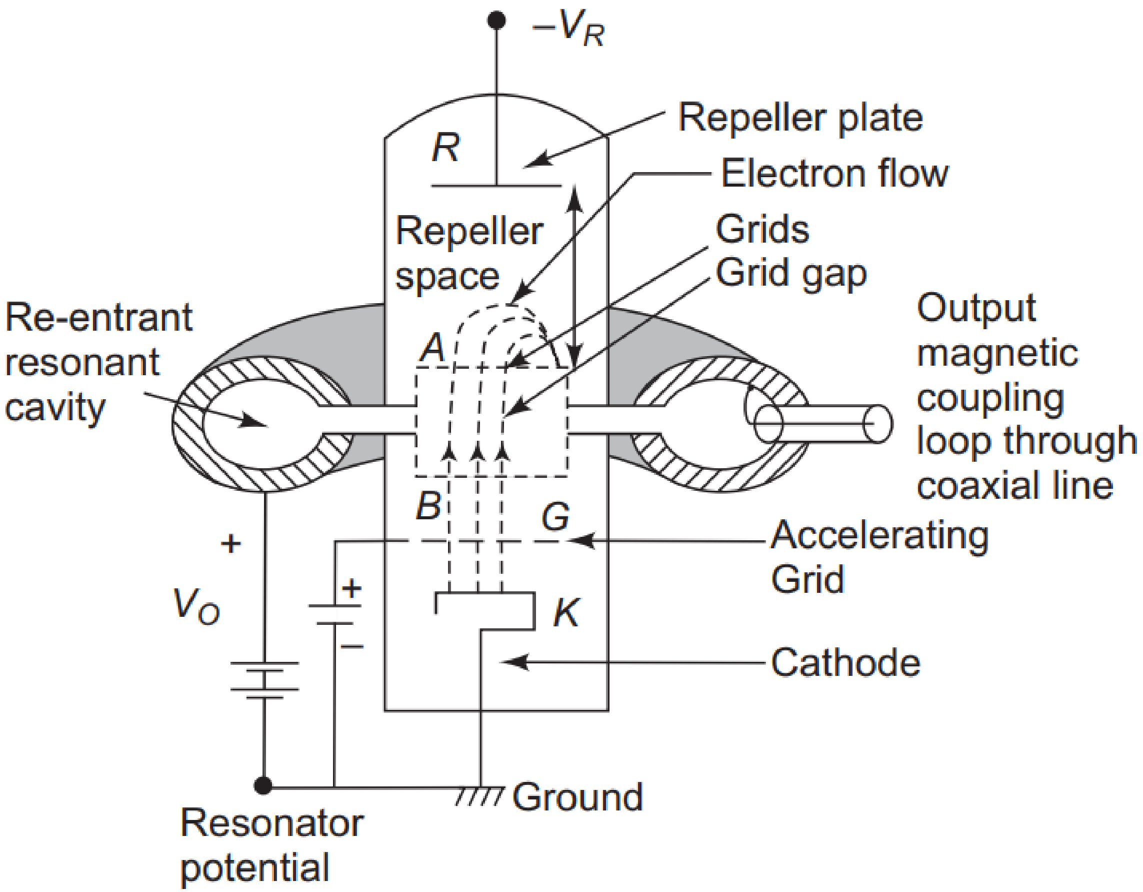
- Cathode K: emits electrons
- Accelerating grid G: accelerates the electrons.



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- Low power microwave oscillator (source)
- Single re-entrant microwave cavity as a resonator.
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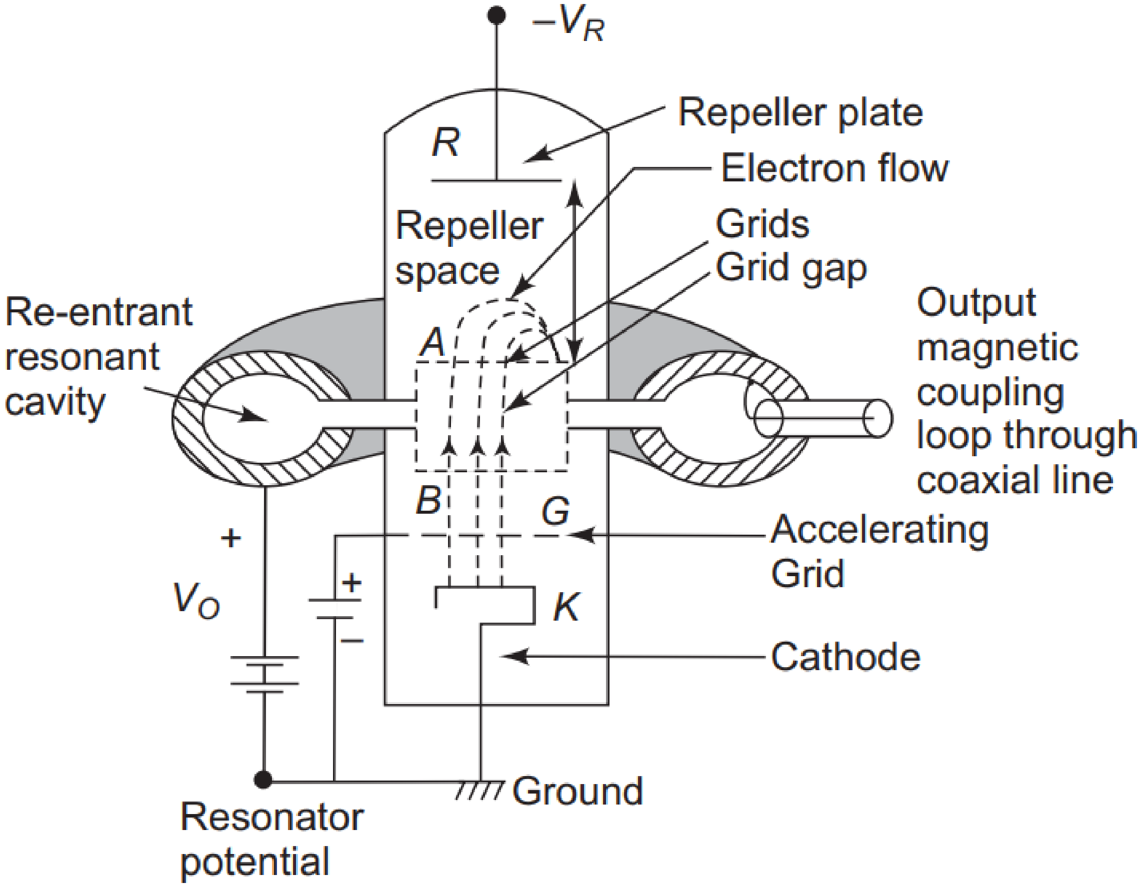
- Accelerating grid G: accelerates the electrons.
- Electron passes through **AB Cavity anode** to the repeller space between **cavity anode AB** and **Repeller plate R**.



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6.1 Reflex Klystron Oscillator

- Feedback maintain the oscillations within cavity by reversing the electron beam by the repeller oscillator.
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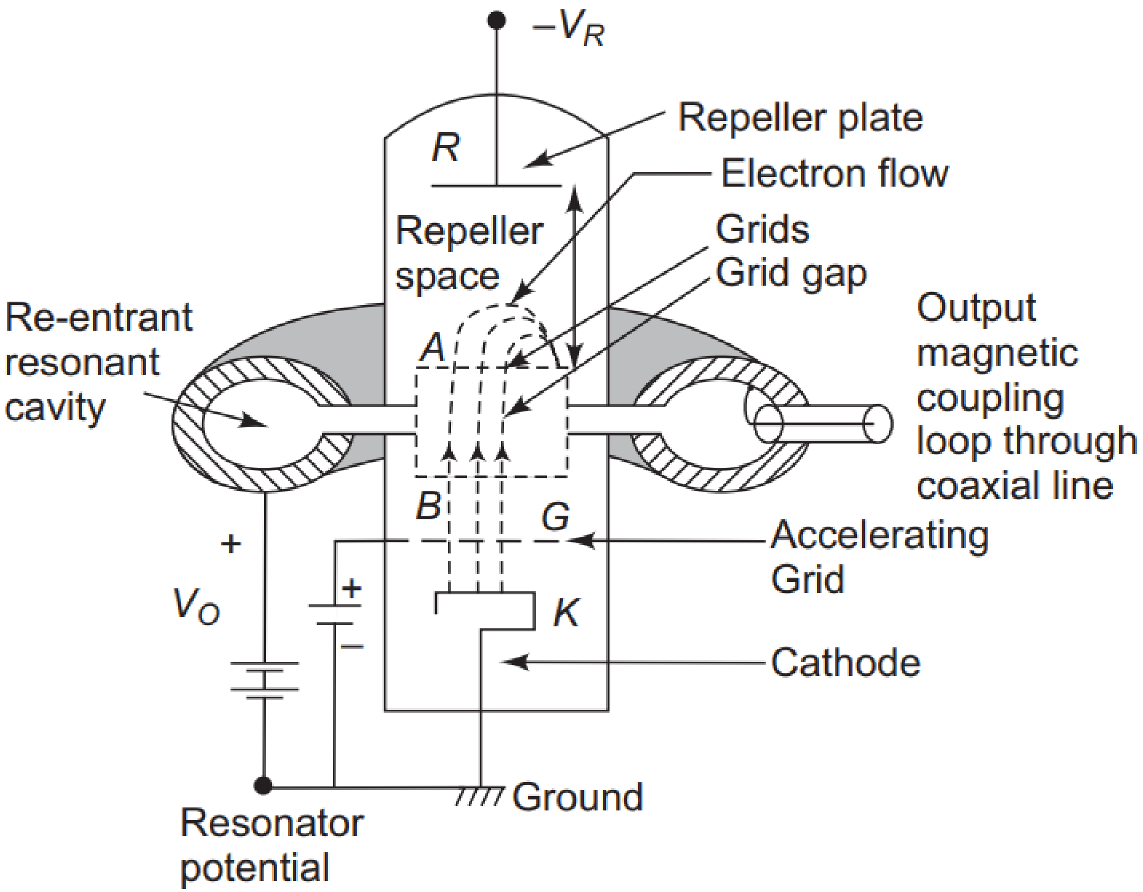

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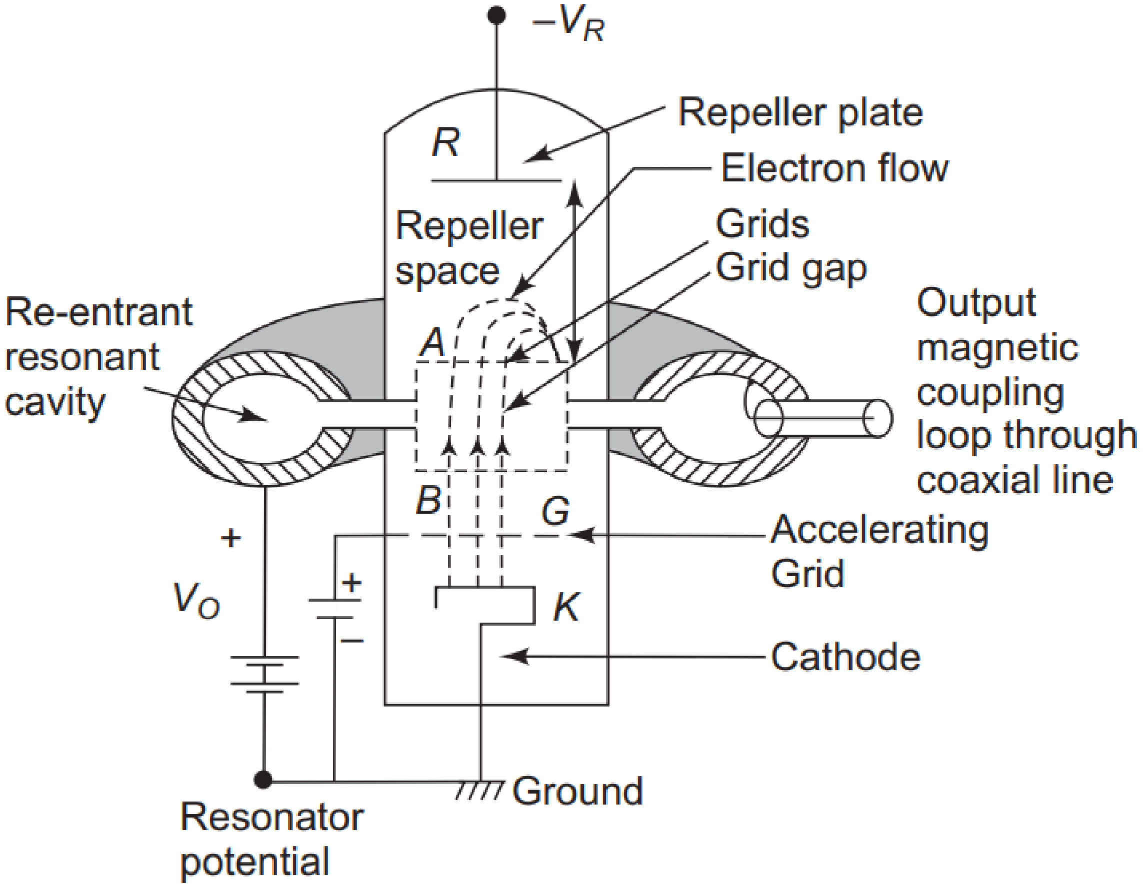
6.1 Reflex Klystron Oscillator

- Feedback maintain the oscillations within cavity by reversing the electron beam by the repeller oscillator.
- **Electrons are velocity modulated** before beam passes though cavity second time, and give energy to cavity and maintain oscillations.



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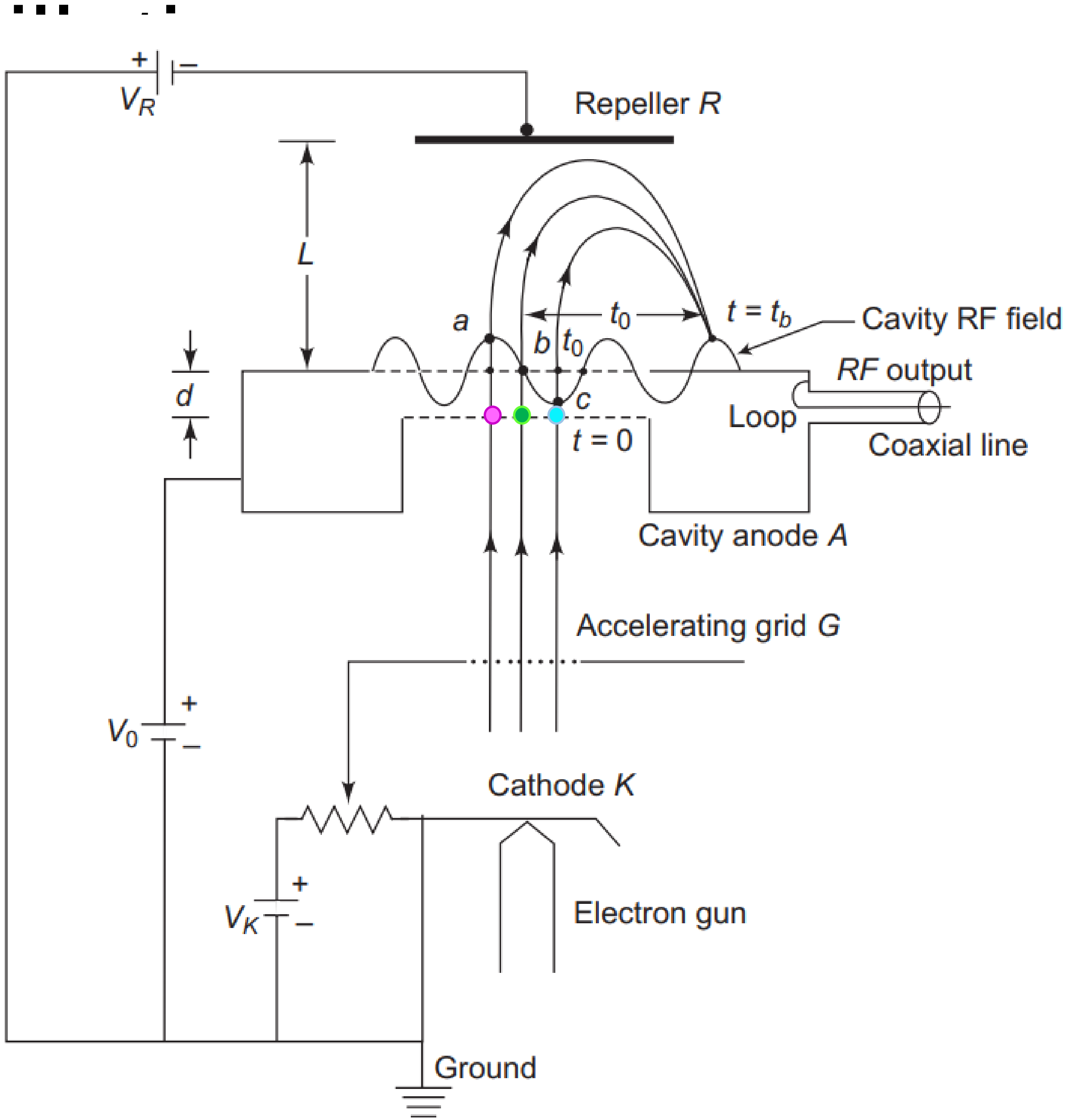
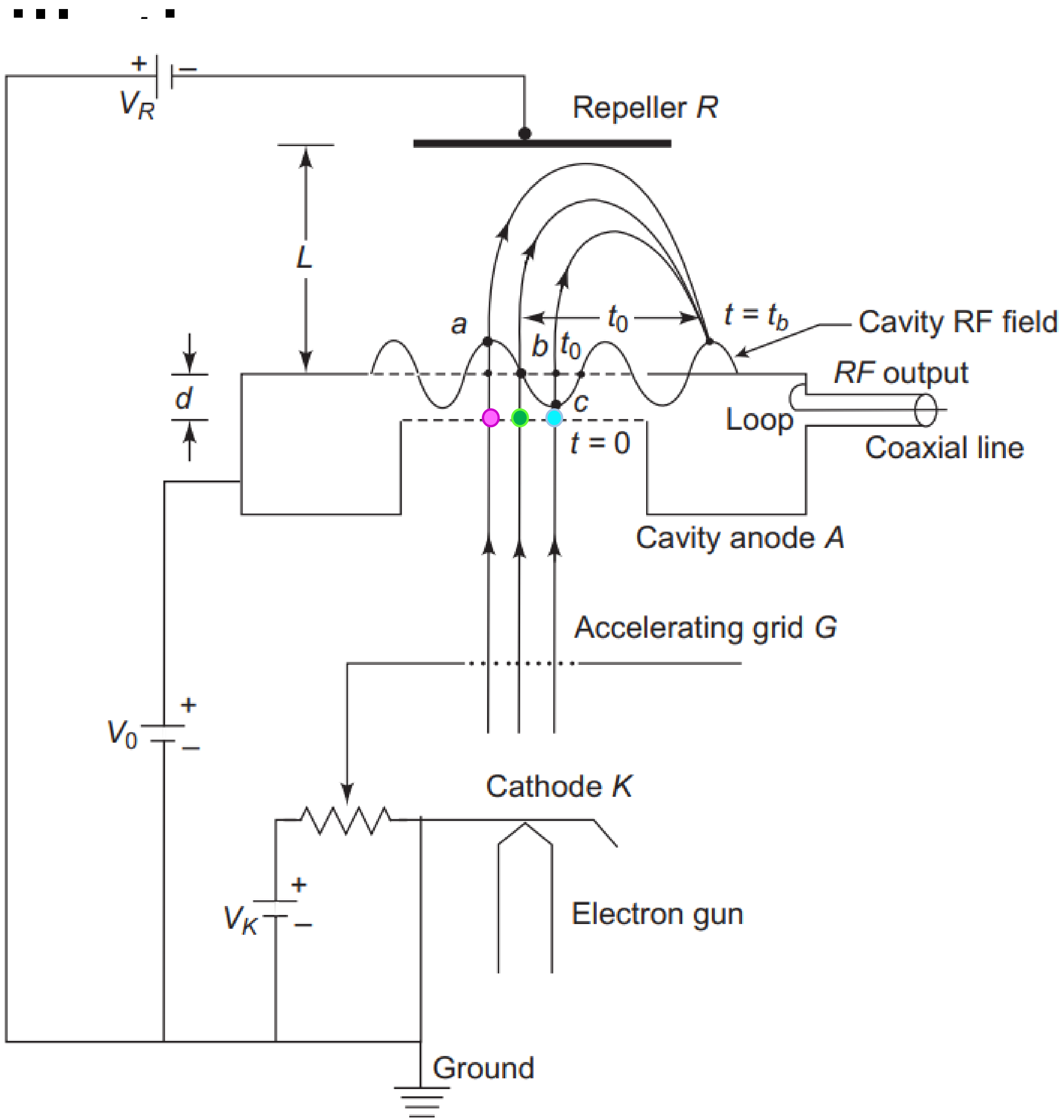
6.2 Mechanism of Os



6.2 Mechanism of Os

- Physical design of the tube controls the number of modes possible



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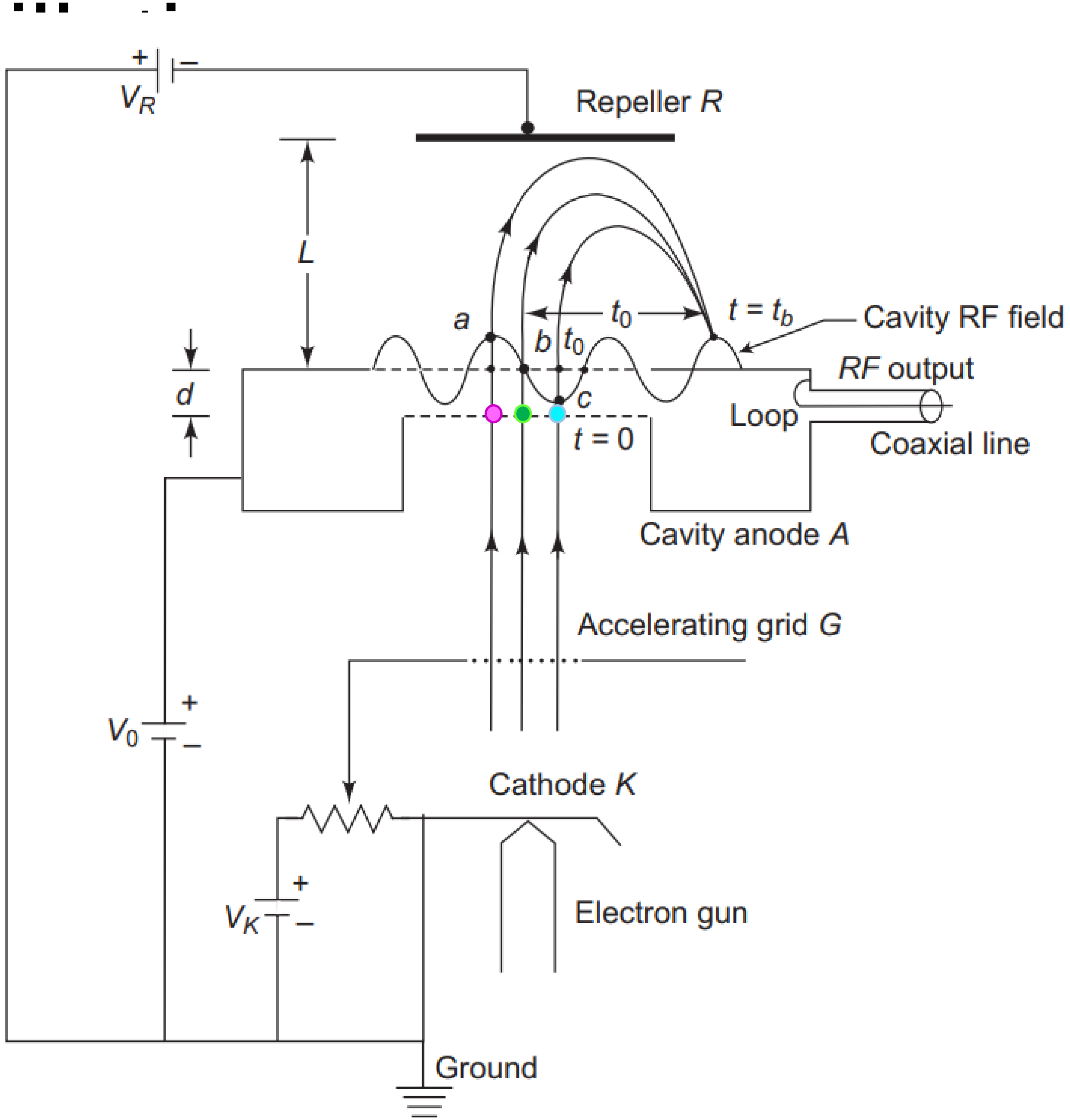
- Normally, a range of 4 modes
- Mode determination: Power available from mode, tunability range



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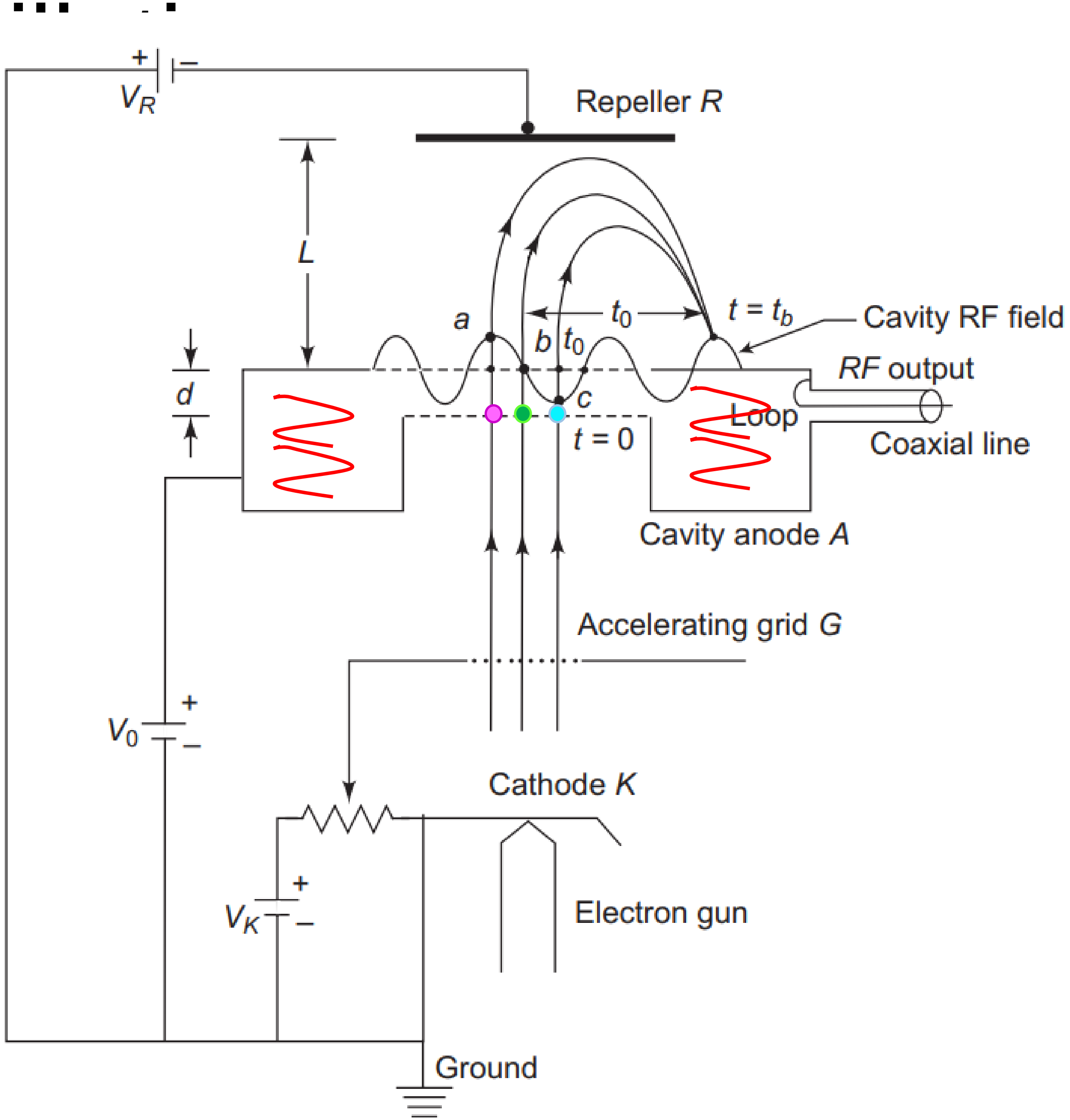
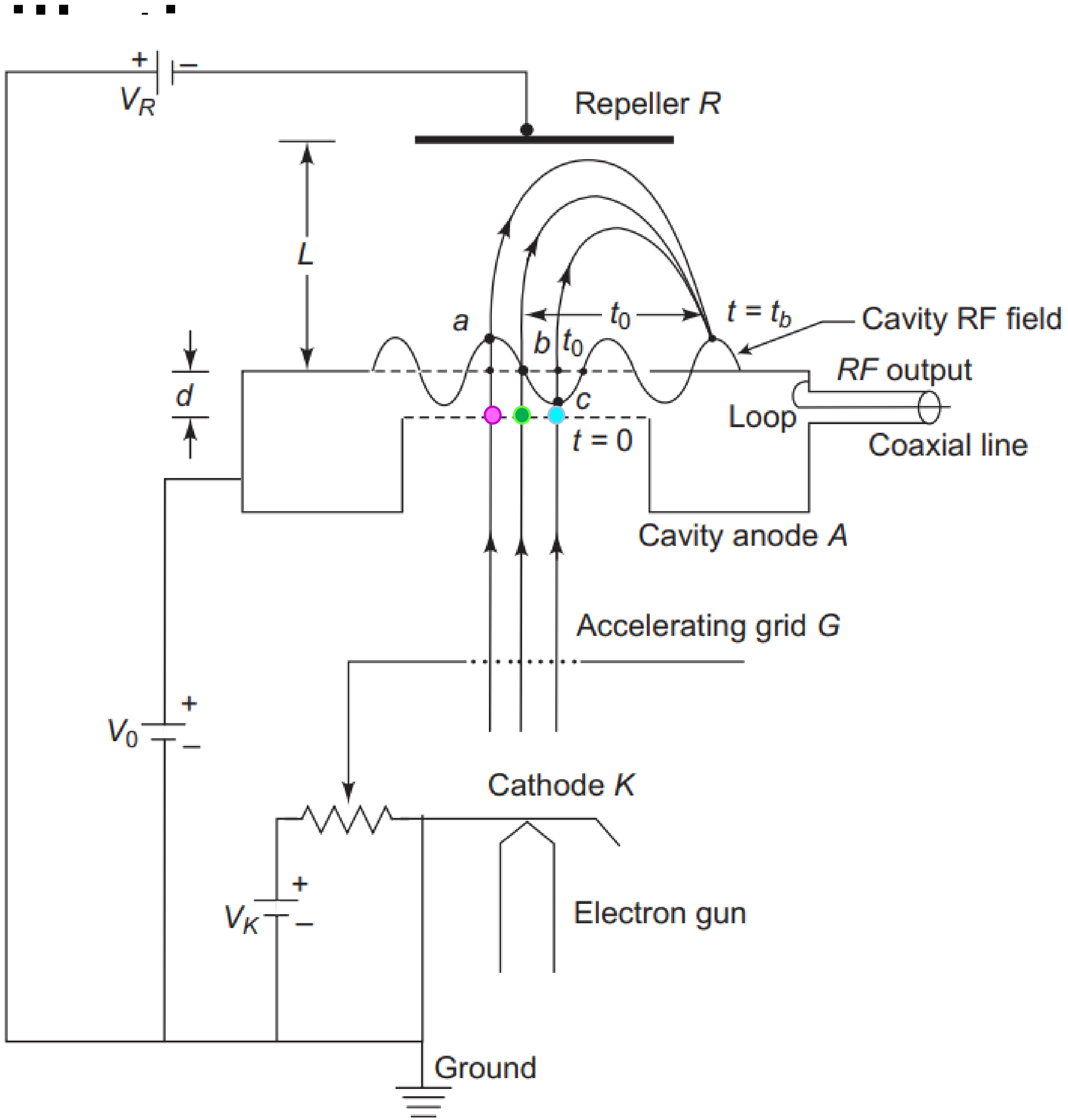
1) RF Noise is generated in the RF cavity due to dc voltage.

2) RF noise -> pronounced to Resonant frequency of cavity.



6.2 Mechanism of Os

3) Electrons passing through the cavity gap d, experience RF field(resonant frequency) and are velocity modulated:



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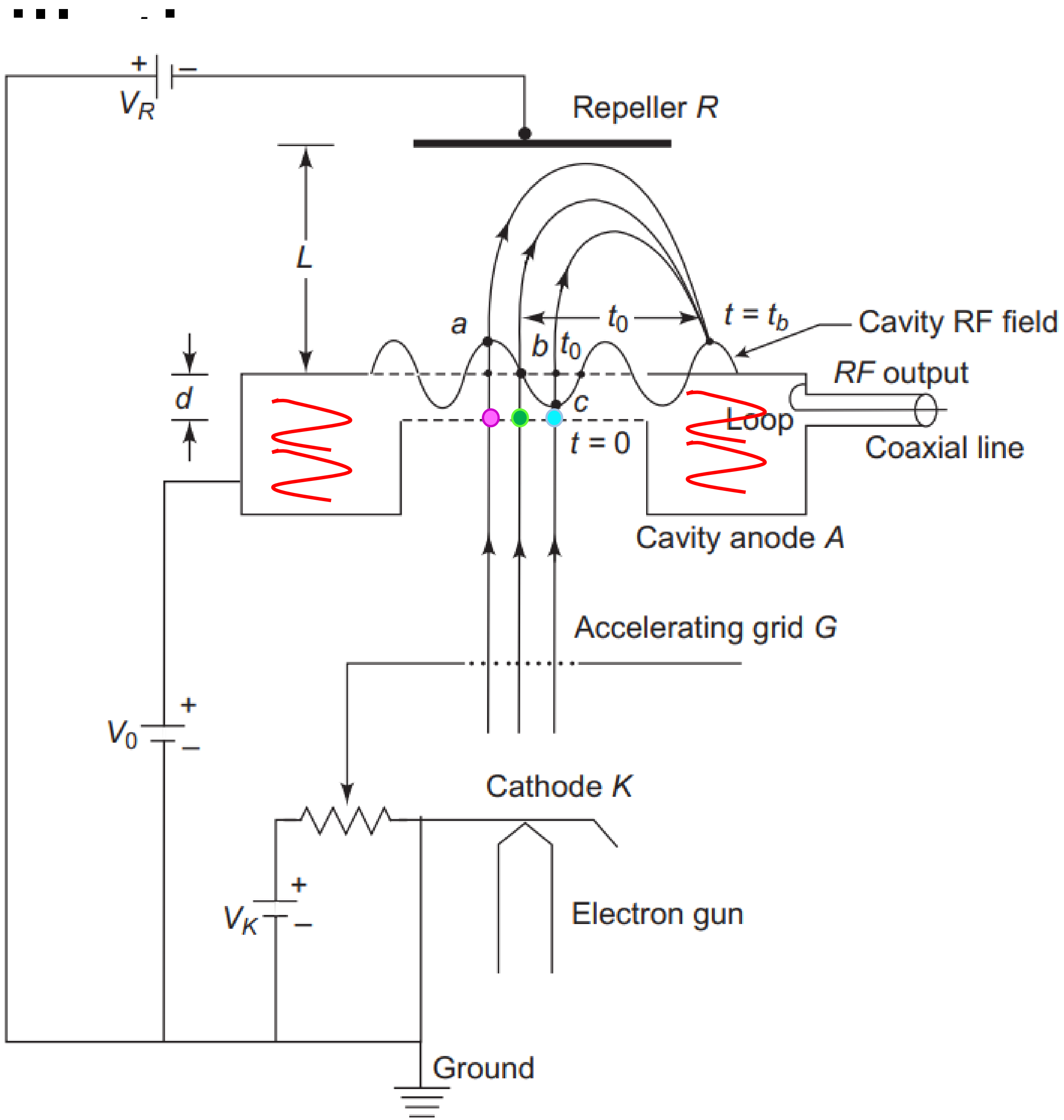

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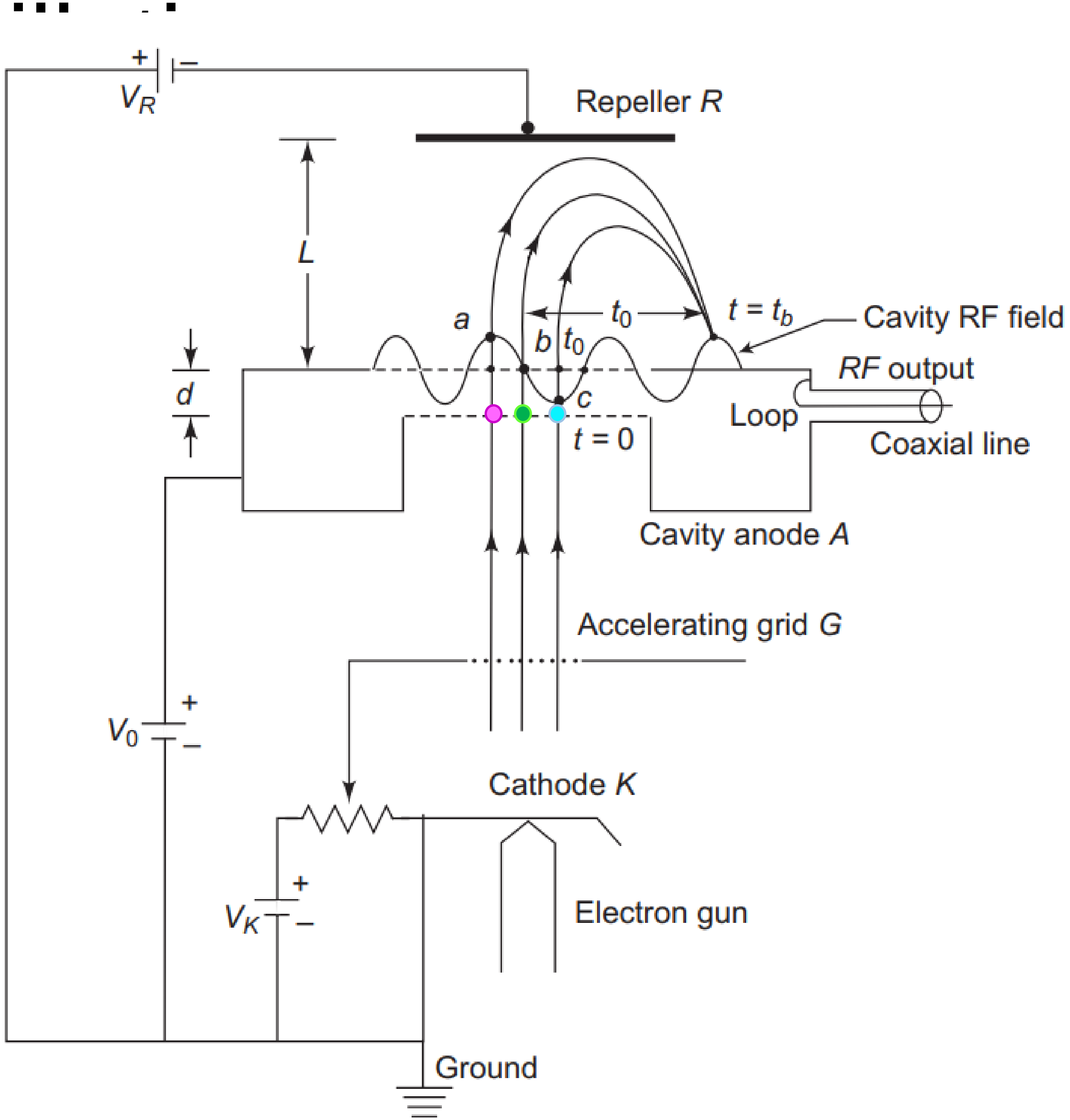
3) Electrons passing through the cavity gap d, experience RF field(resonant frequency) and are velocity modulated:

i) acceleration of electrons a aligned with positive half cycle of RF field in cavity gap

ii) unchanged original velocity of electrons b which encountered zero RF field.



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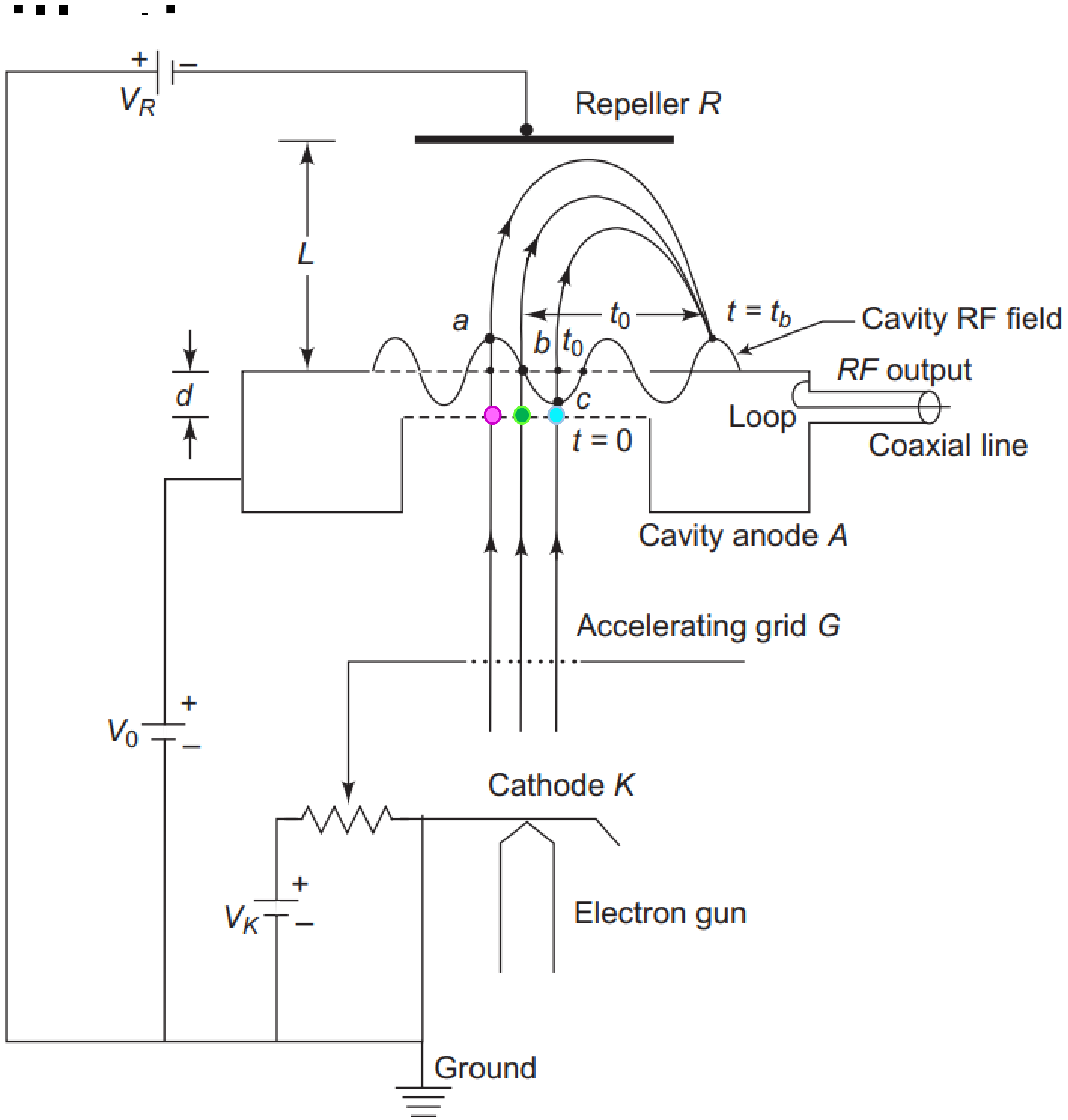
3) Electrons passing through the cavity gap d, experience RF field(resonant frequency) and are velocity modulated:

i) acceleration of electrons a aligned with positive half cycle of RF field in cavity gap

ii) unchanged original velocity of electrons b which encountered zero RF field.

iii) deceleration/retardation of electrons c which encountered negative half cycle



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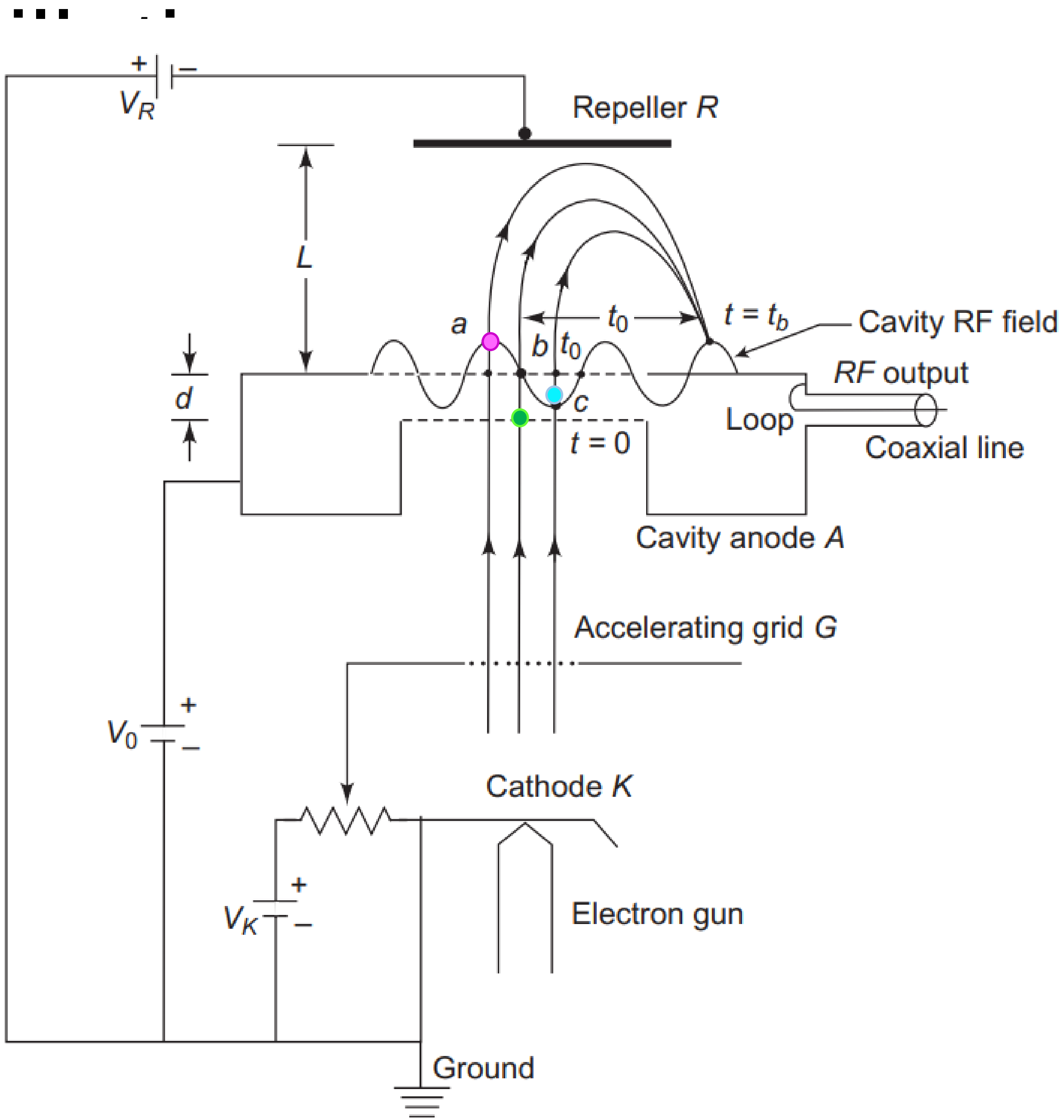
4) Velocity modulated electrons enter the repeller space and are repelled back to the cavity by Repeller R due to its negative potential.



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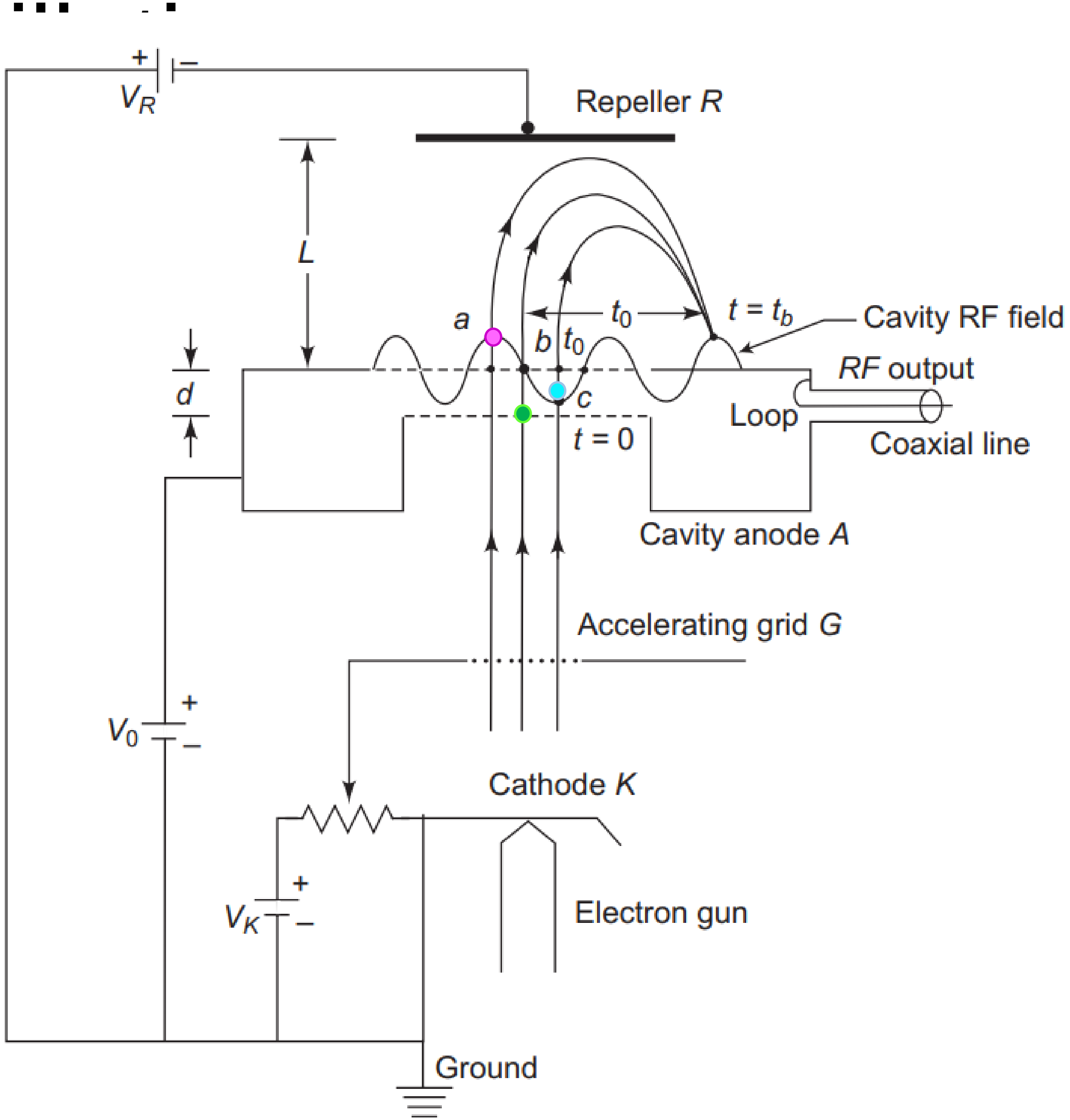
4) Velocity modulated electrons enter the repeller space and are repelled back to the cavity by Repeller R due to its negative potential.

5) Repeller space L and Repeller voltage V_R can be adjusted to receive all velocity modulated electrons at same time on positive peak of cavity RF cycle.



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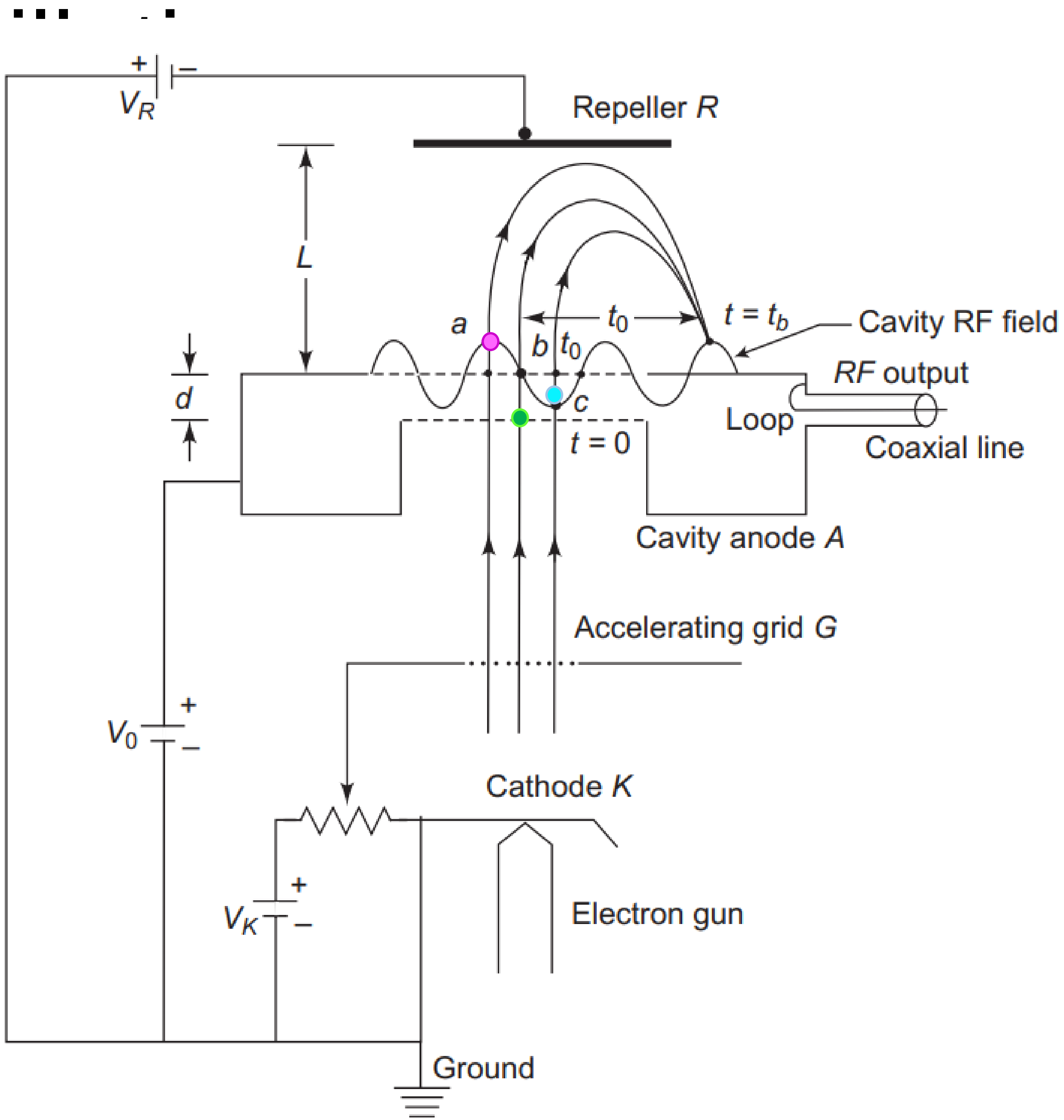
6) Velocity modulated electrons are bunched together -> Lose kinetic energy when they encounter positive cycle of cavity RF field.



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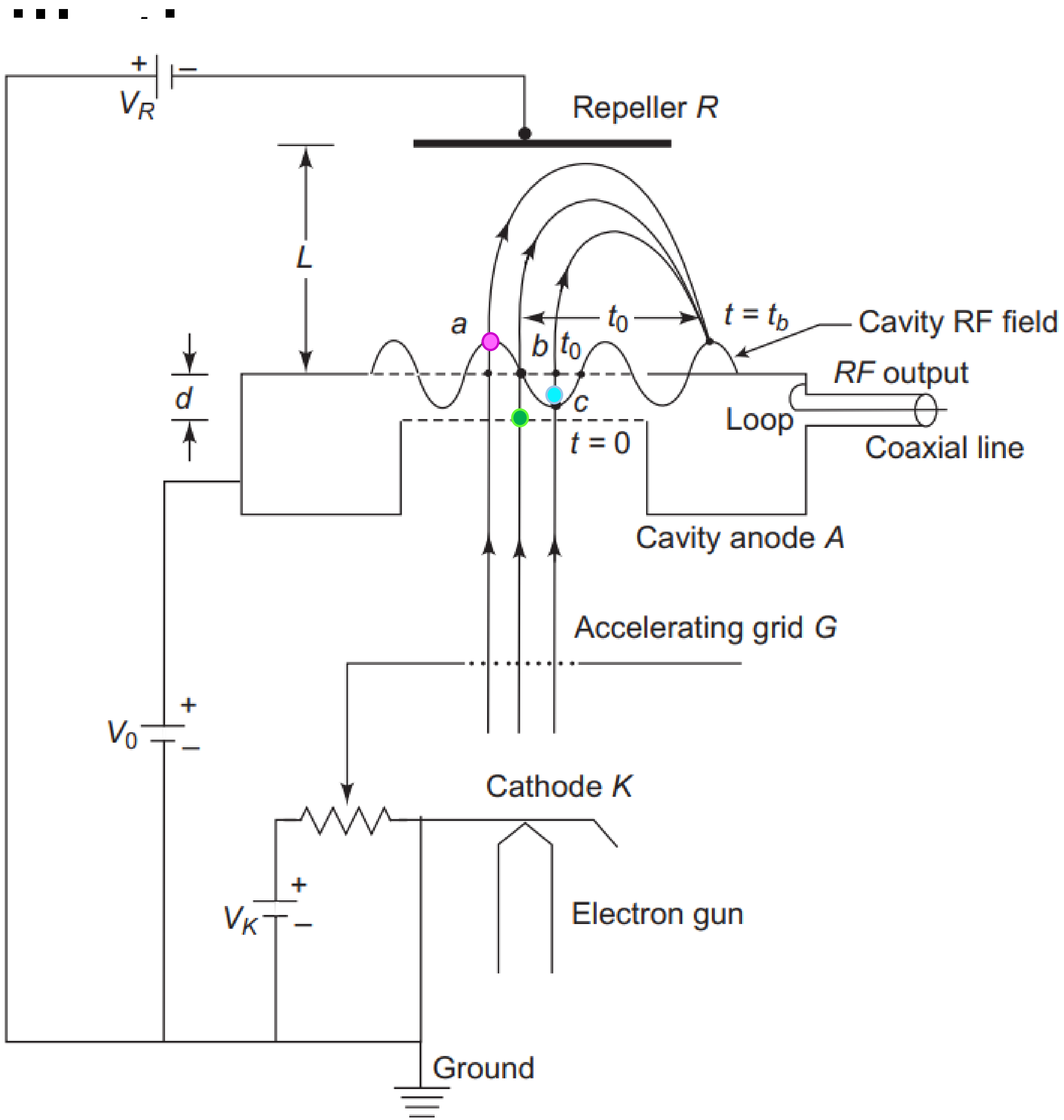
7) Lost kinetic energy – transferred to cavity to conserve total power.



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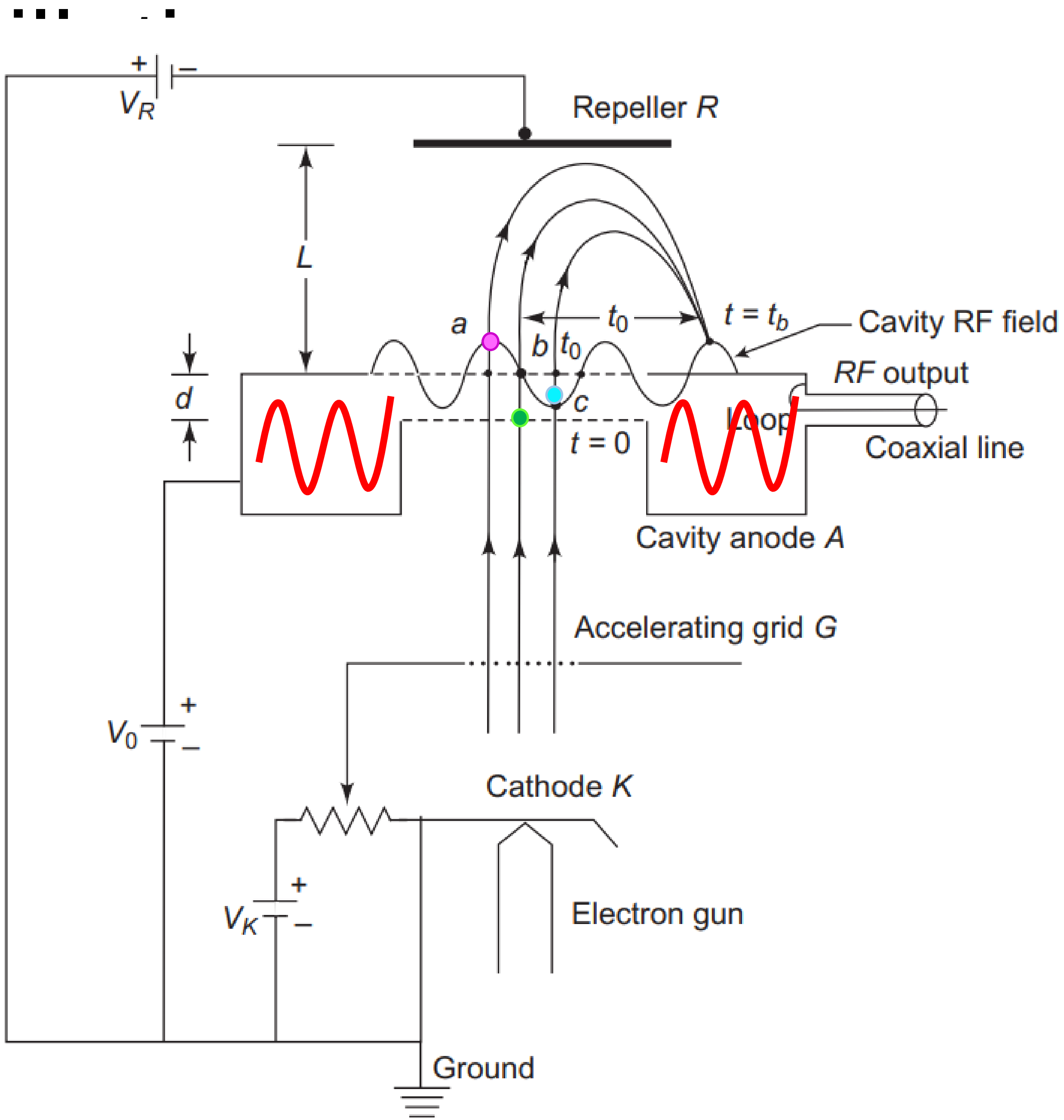
8) When RF power delivered by bunched electrons to cavity is greater than cavity power loss, EM field amplitude (resonant frequency of cavity) will increase to produce microwave oscillations, and are maintained at resonant frequency of the cavity.



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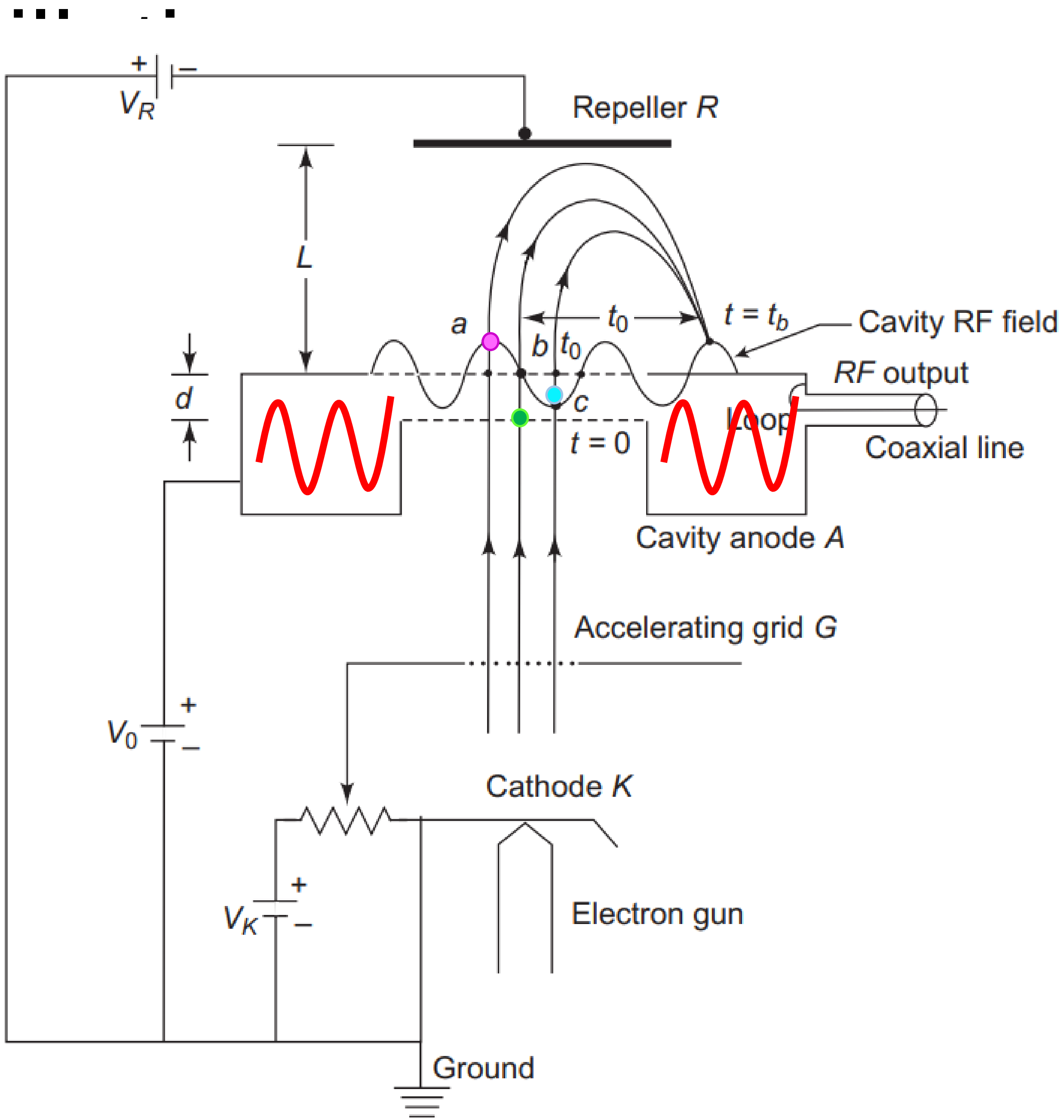
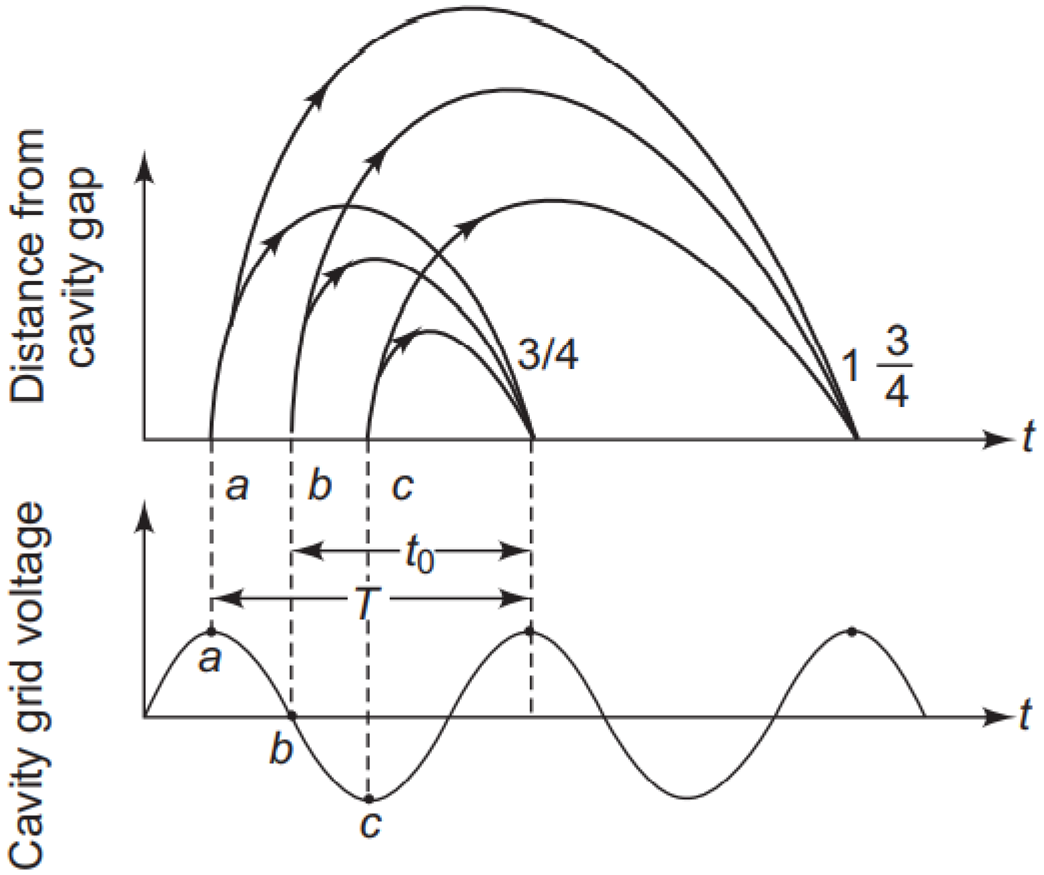
8) When RF power delivered by bunched electrons to cavity is greater than cavity power loss, EM field amplitude (resonant frequency of cavity) will increase to produce microwave oscillations, and are maintained at resonant frequency of the cavity.

9) RF power is coupled to output load by small loop formed from central conductor of coaxial line.



6.3 Mode of oscillation

Bunched electrons in reflex klystron can deliver max power to cavity at any positive peak of RF cycle of cavity oscillation.



Source: Book by Annapurna Das

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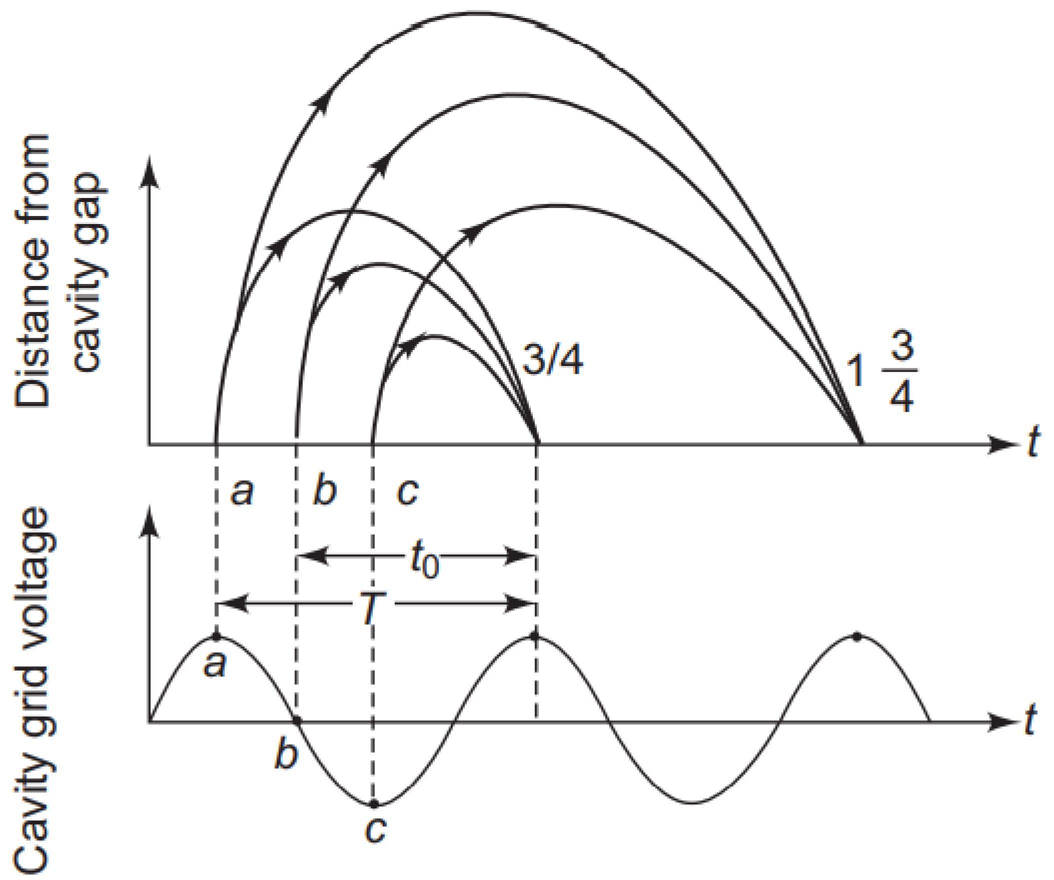
T: time period at resonant frequency

t_0: time taken by reference electron to travel in repeller space (Entering repeller space at b and returning to cavity at positive peak viltage when bunch is formed.



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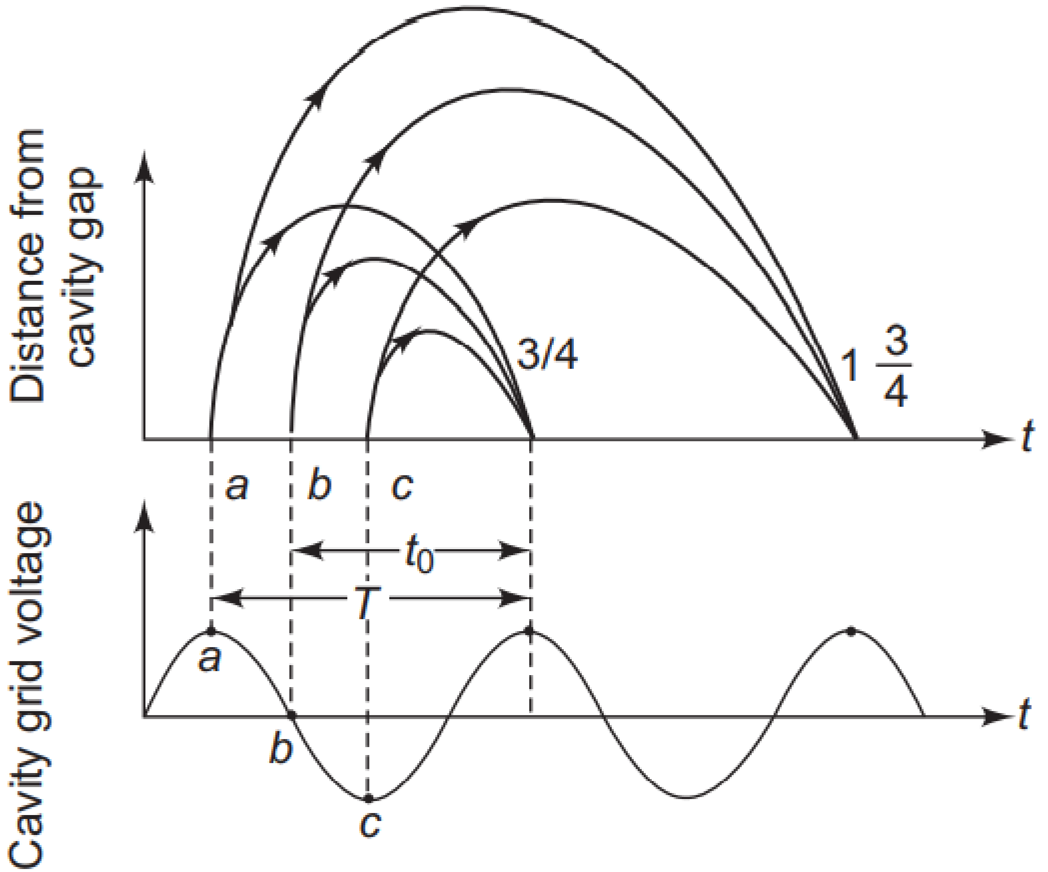
- $t_0 = (n + 3/4)T = NT$

Modes of oscillation $N = n + 3/4 \;\; N = \frac{3}{4}, 1\frac{3}{4}, 2\frac{3}{4}$, etc

With modes $n = 0,1,2,3$



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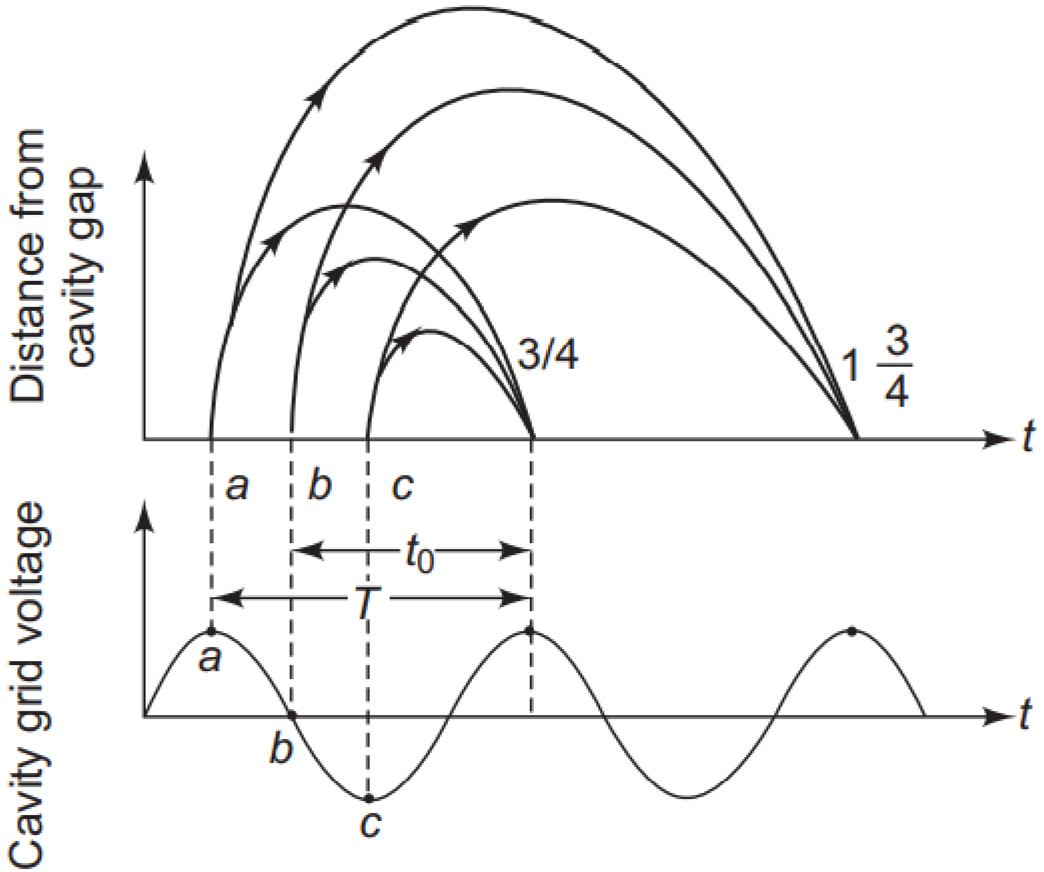

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- (for fixed repeller space): Adjust the repeller voltage bunching to make the bunch occur at $N = n + 3/4$ positive half cycle.

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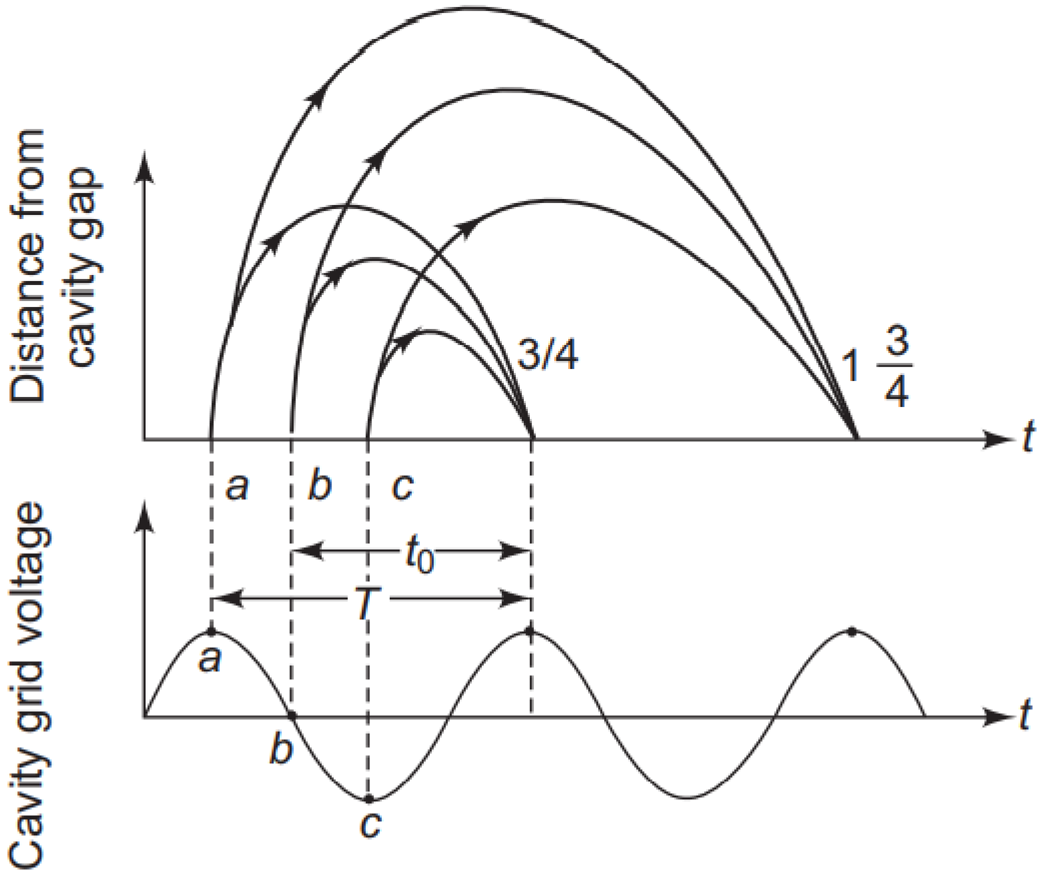

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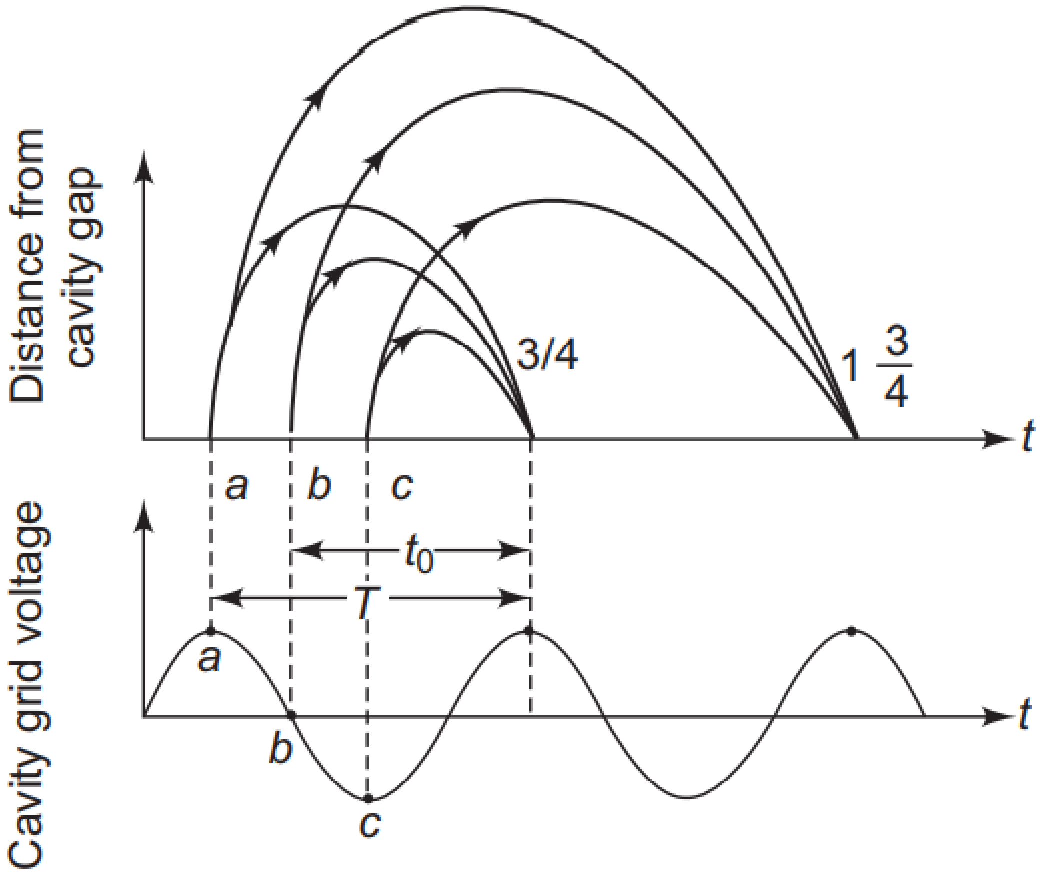
Lowest order mode : Max repeller voltage - t_0: transit time – Maximum acceleration of bunched electrons on return – Output power is maximum



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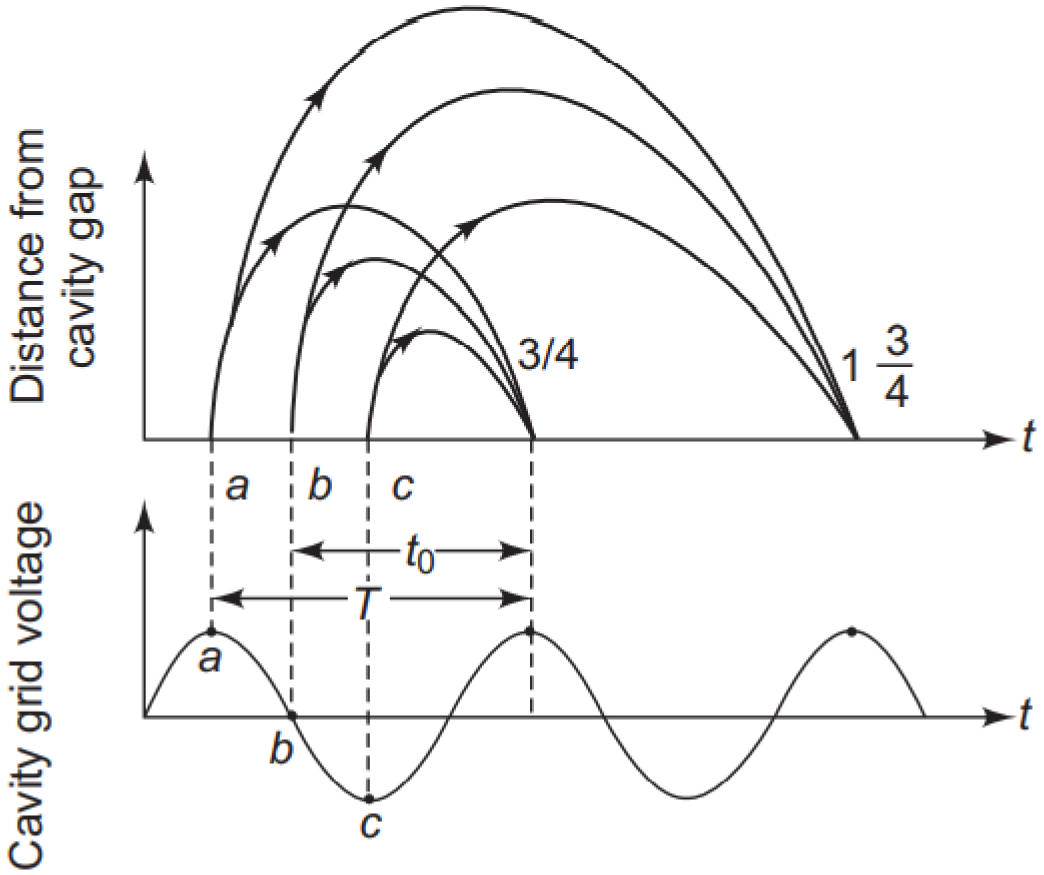

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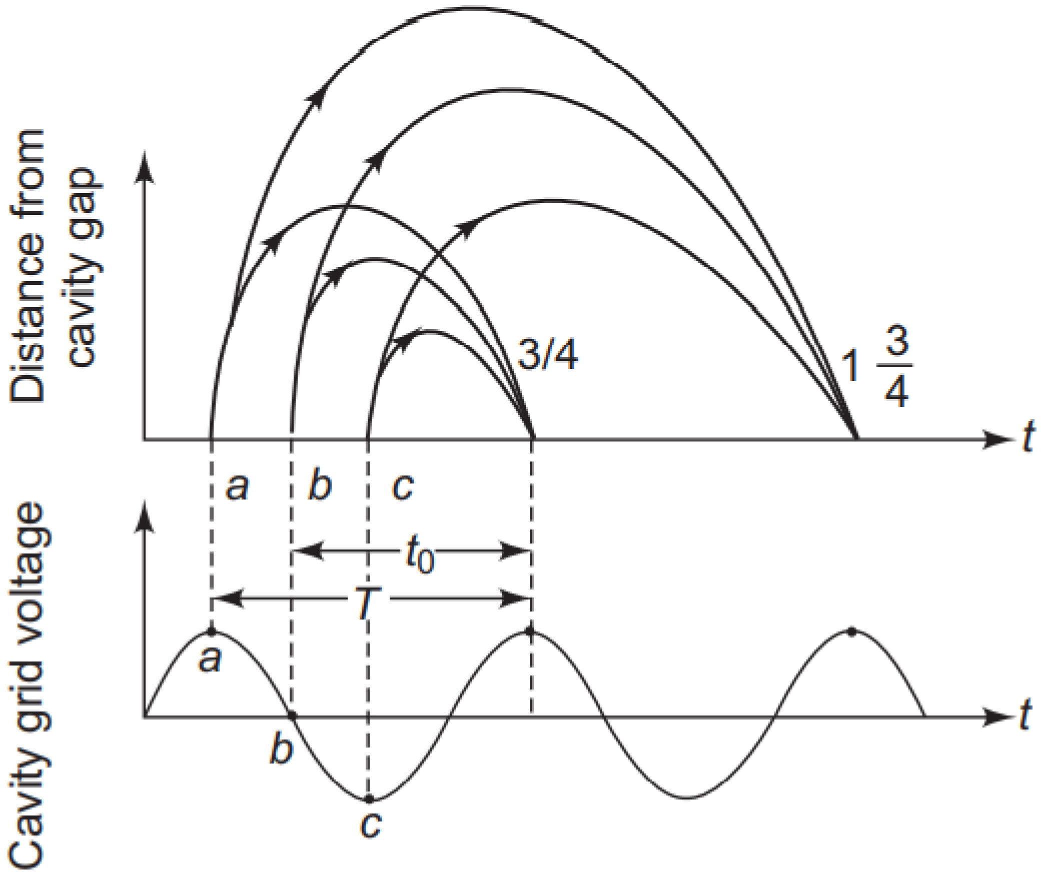
Lowest order mode : Max repeller voltage - t_0: transit time – Maximum acceleration of bunched electrons on return – Output power is maximum

Higher order modes: Low repeller voltages – low acceleration of electrons – low output power.

6.4 Velocity modulation

Assumptions:

1) Cavity grids and repeller are plane parallel and very large in extent
2) No RF field is excited in repeller space
3) Electrons are not intercepted by the cavity anode grid



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Assumptions:

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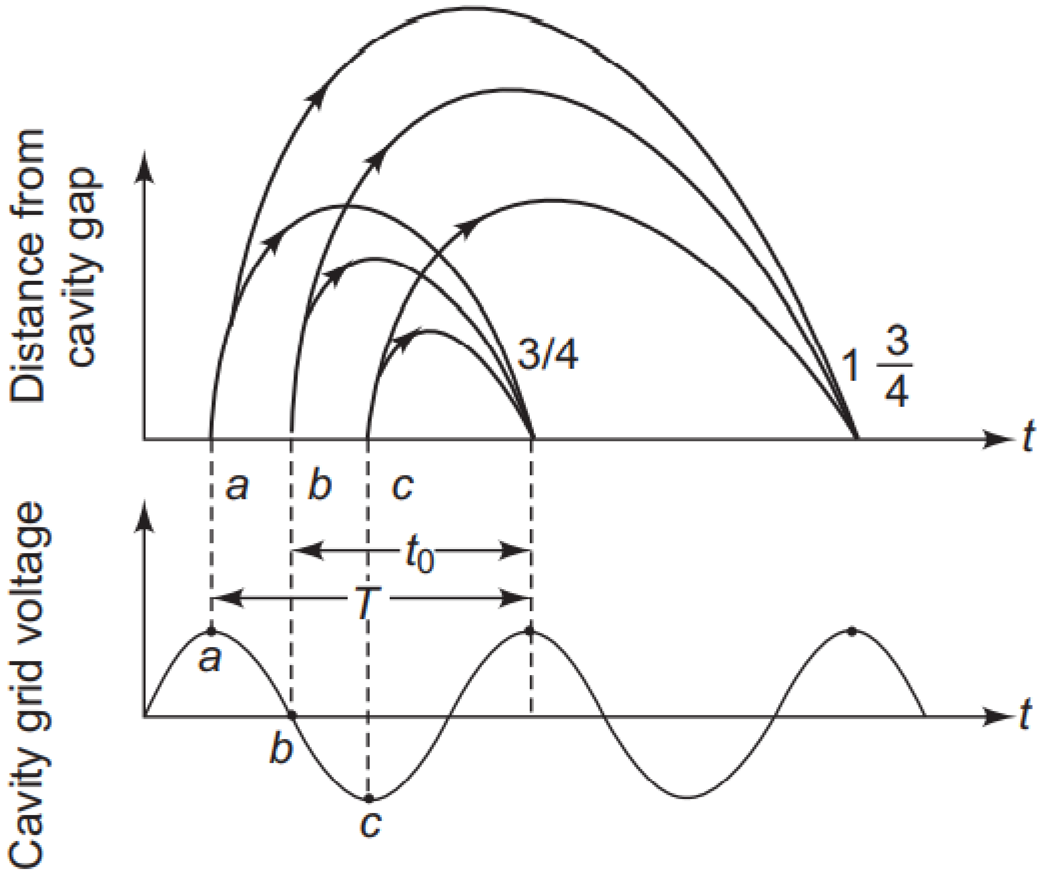
2) No RF field is excited in repeller space
3) Electrons are not intercepted by the cavity anode grid
4) No debunching takes place in the repeller space
5) Cavity RF gap voltage amplitude V_1 is small compared to the dc beam voltage V_0



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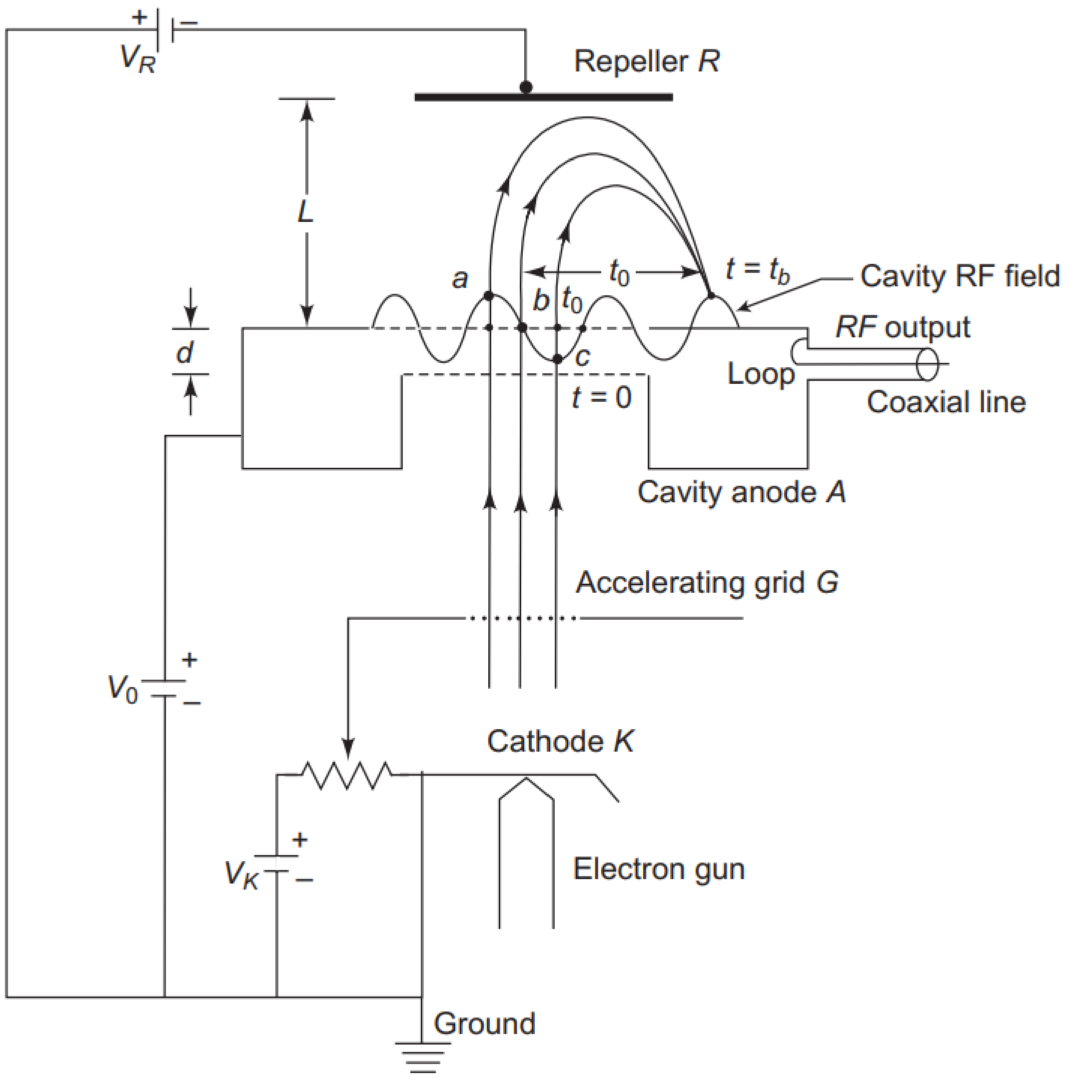
6.4 Velocity modulation

- Electron velocity u attained due to dc beam voltage V_0 while entering cavity gap at $t = 0$ is uniform

$$\frac{1}{2}mu^2 = eV_0 \qquad u = u_0 = \sqrt{\left(\frac{2eV_0}{m}\right)}$$
$$= 5.93 \times 10^5\sqrt{V_0}\ \text{m/s}$$

- V_0 is in volts, $u = 0$ at cathode surface.



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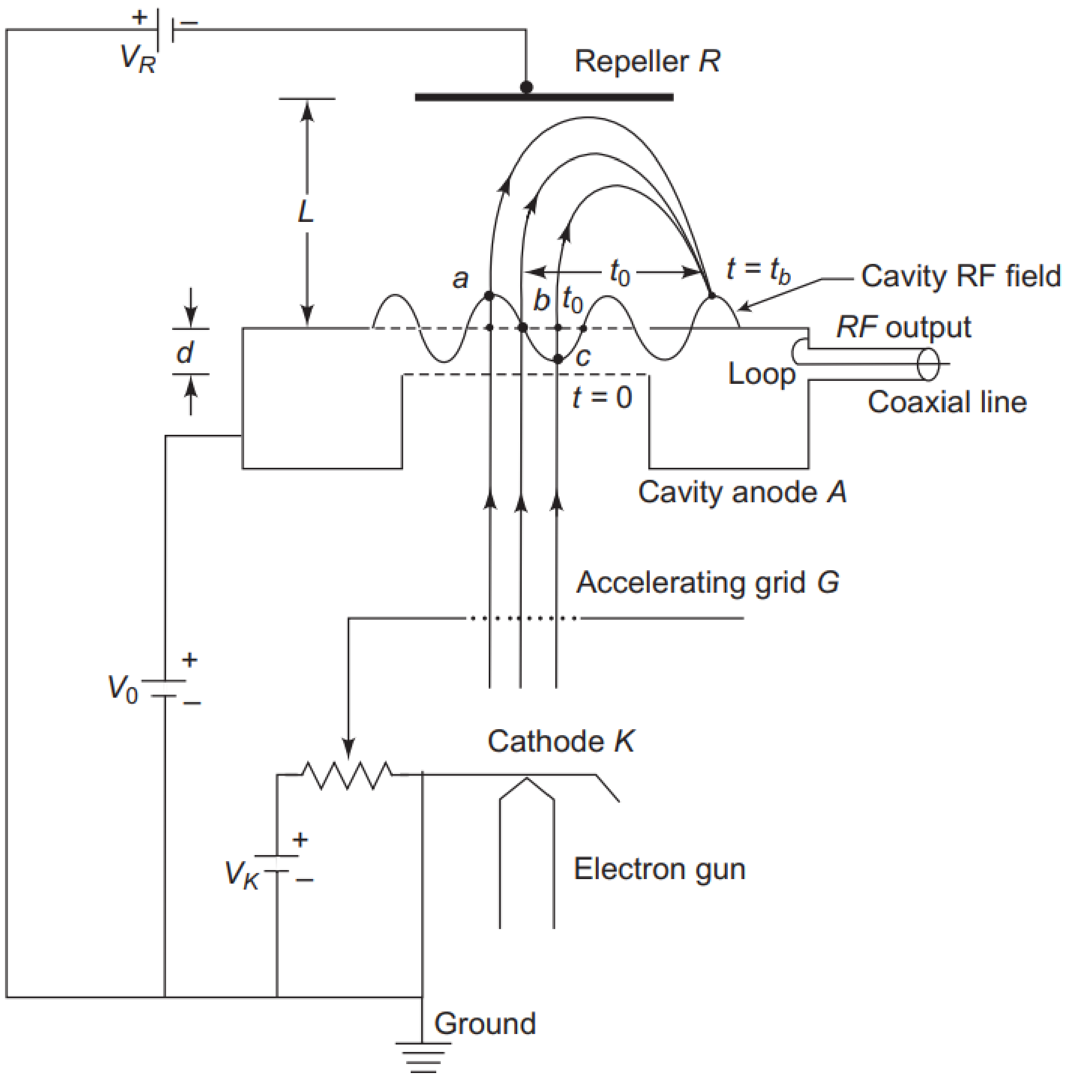
- Instantaneous cavity RF voltage

$V(t) = V_1 \sin \omega t$ where $V_1 \ll V_0$



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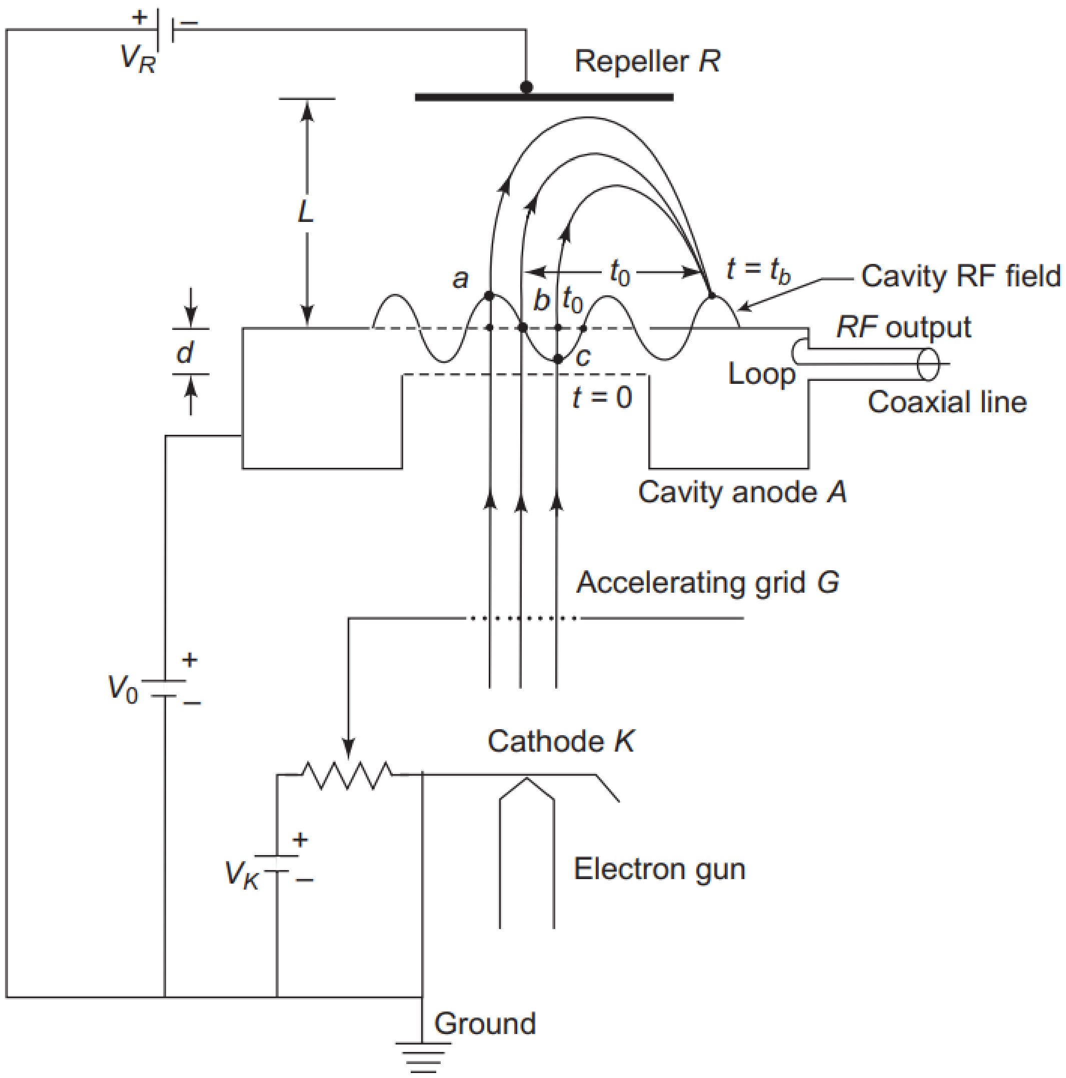
$V(t) = V_1 \sin \omega t$ where $V_1 \ll V_0$

- Average transit time through cavity gap d

$$t_g = \frac{d}{u_0}$$

- transit angle $\theta_g = \omega t_g = \omega d/u_0$

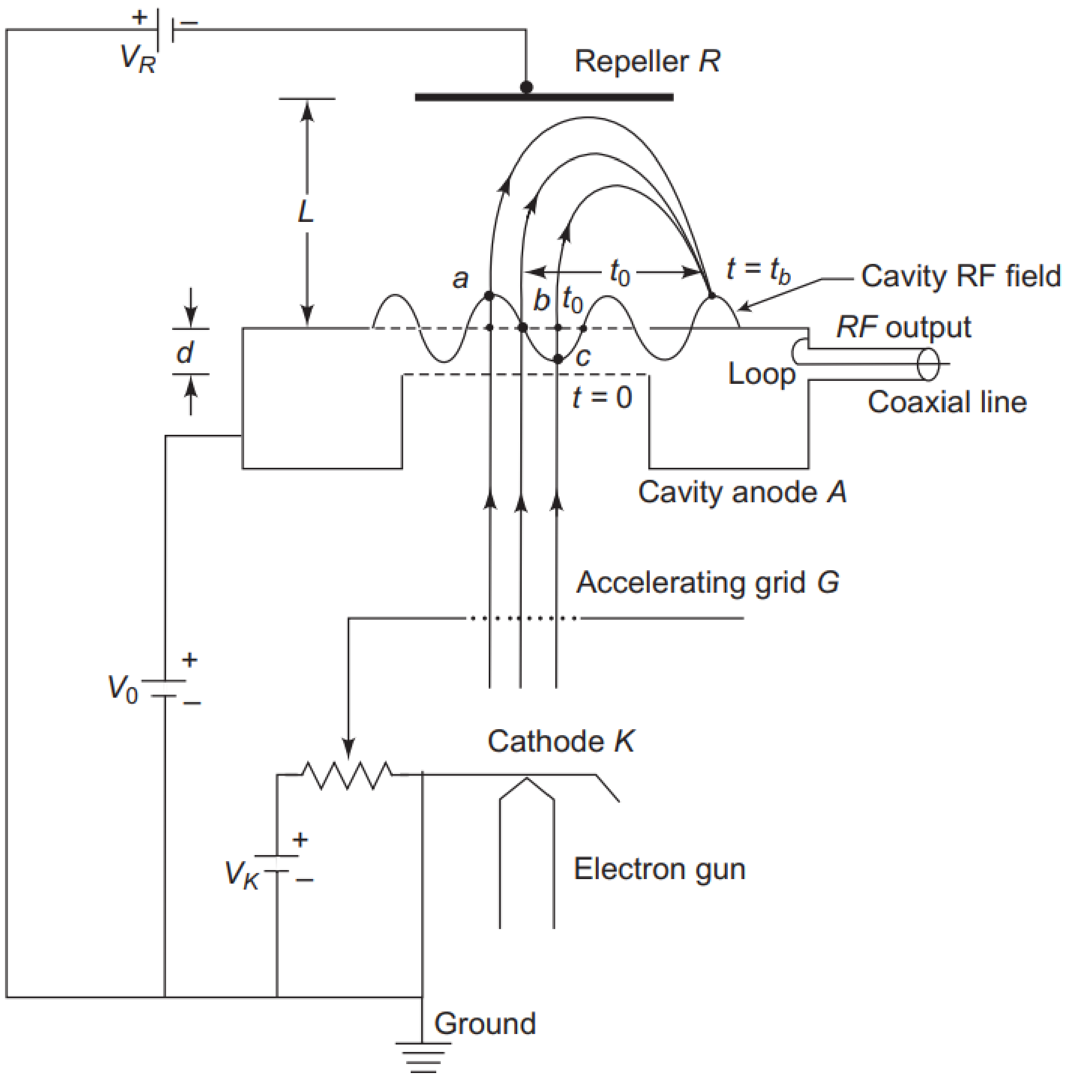


6.4 Velocity modulation

- Average microwave voltage in cavity gap

$$V_{av} = \frac{1}{t_g}\int_0^{t_g} V_1 \sin \omega t \ dt = \frac{V_1[1-\cos \omega t_g]}{\omega t_g}$$

$$=$$



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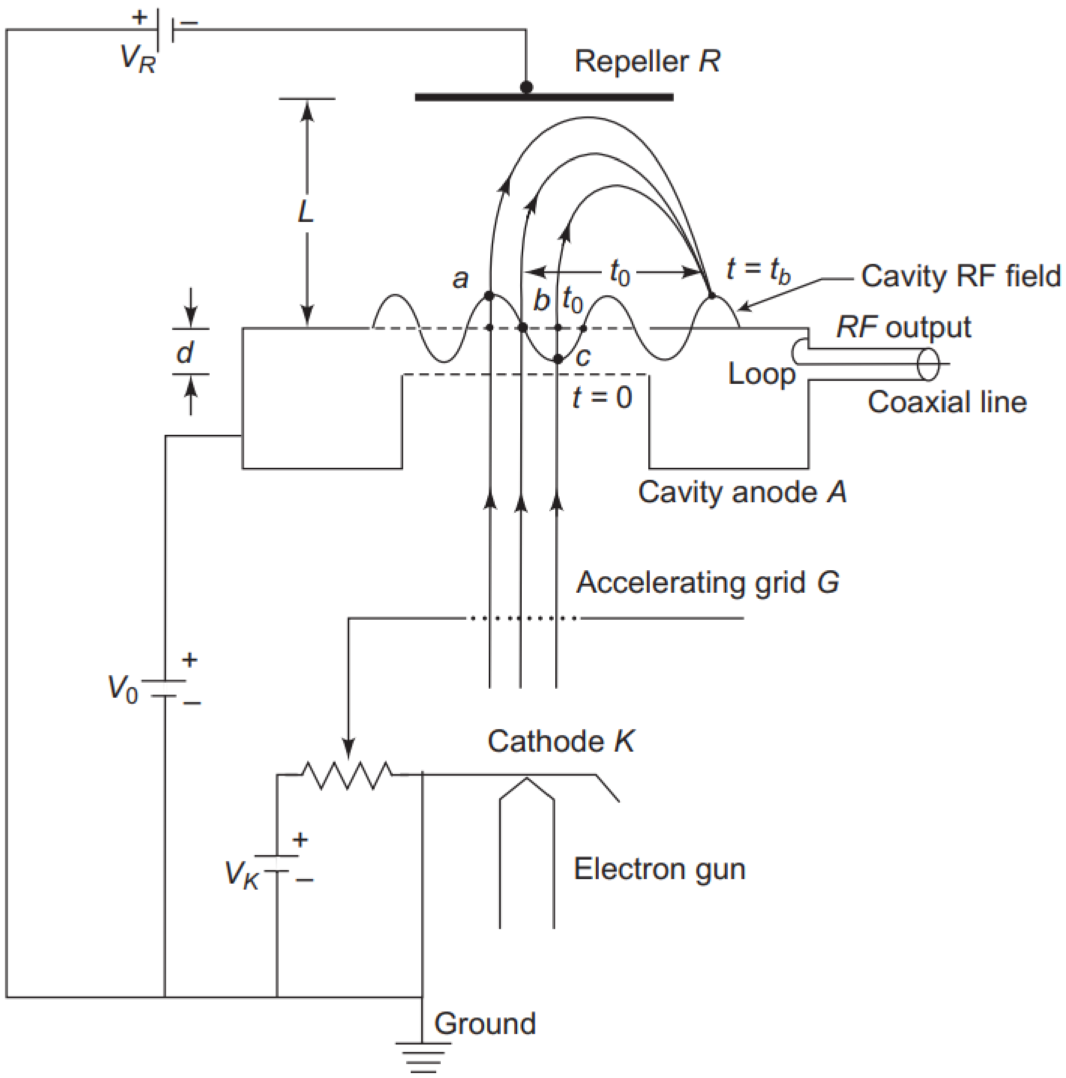

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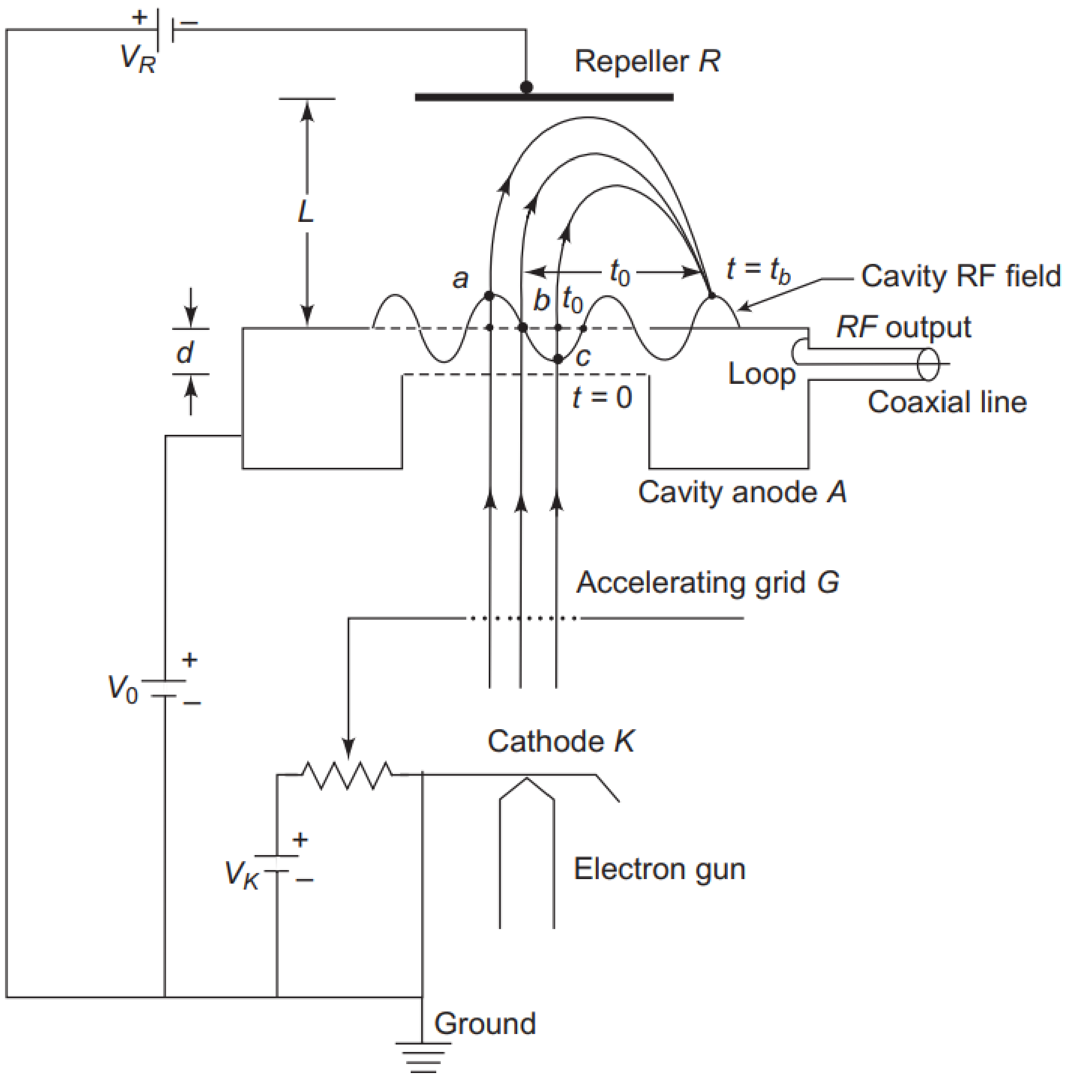
Where $\beta_1 = \frac{sin\left(\frac{\theta_g}{2}\right)}{\theta_g/2} = \frac{sin\left(\frac{\omega d}{2u_0}\right)}{\omega d/2u_0}$ is beam coupling coefficient of the cavity gap



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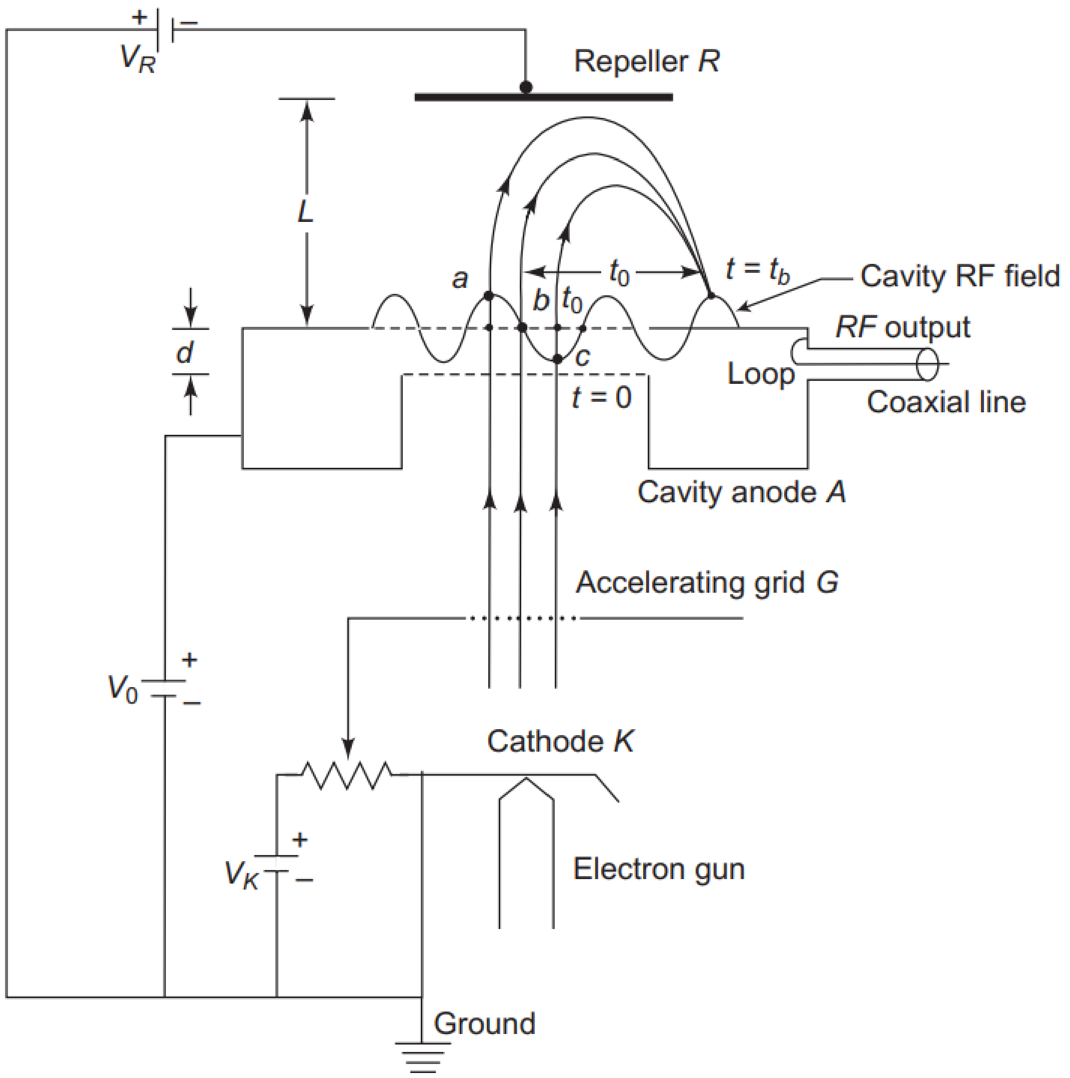
- Coupling between electron beam and cavity varies with cavity gap d is $\frac{\sin X}{X}$ form.



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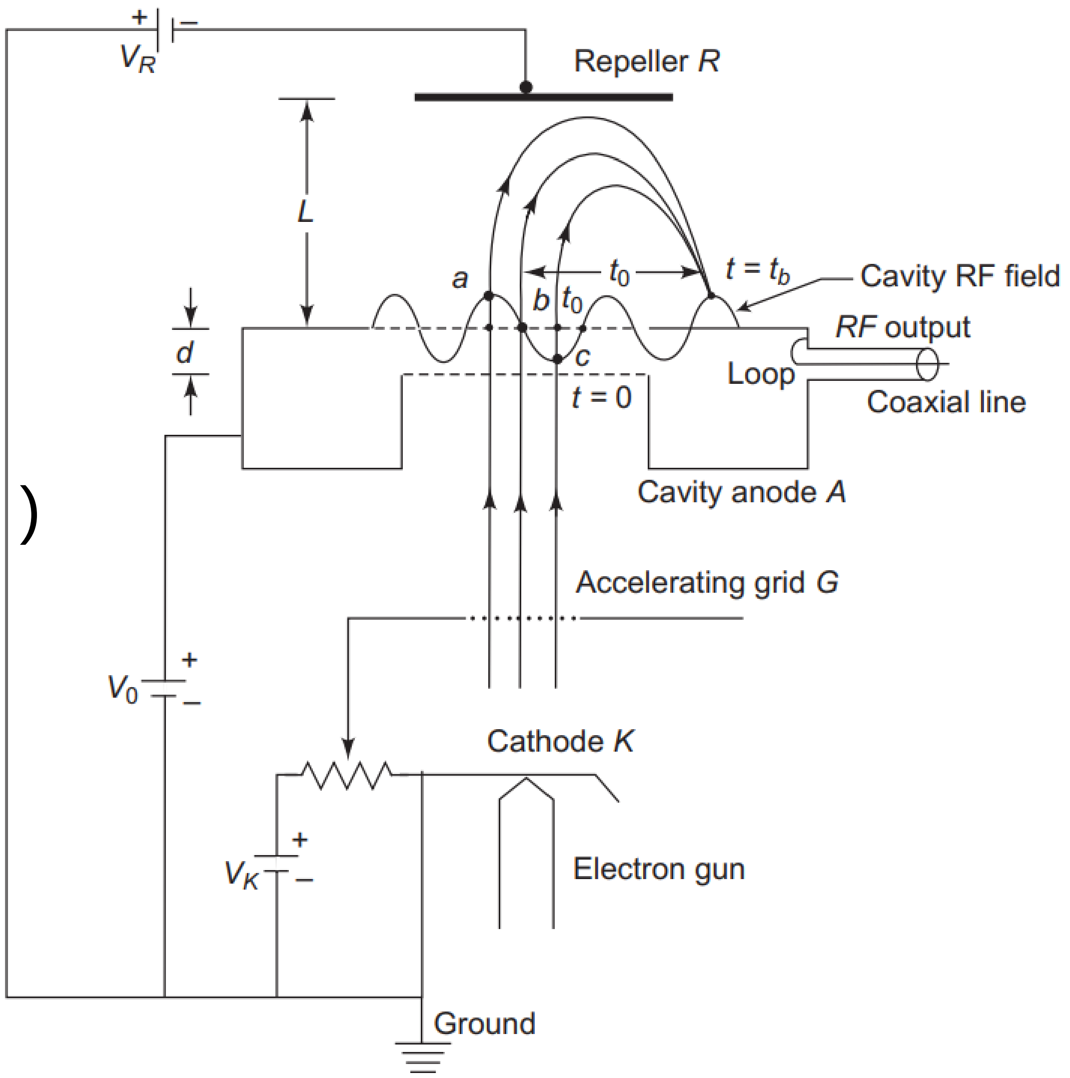
Exit velocity from cavity gap ($\frac{1}{2}mu^2 = e(V_{av} + V_0)$)

$$u(t_g) = \sqrt{[2e(V_0 + V_{av})/m]}$$

$$=$$



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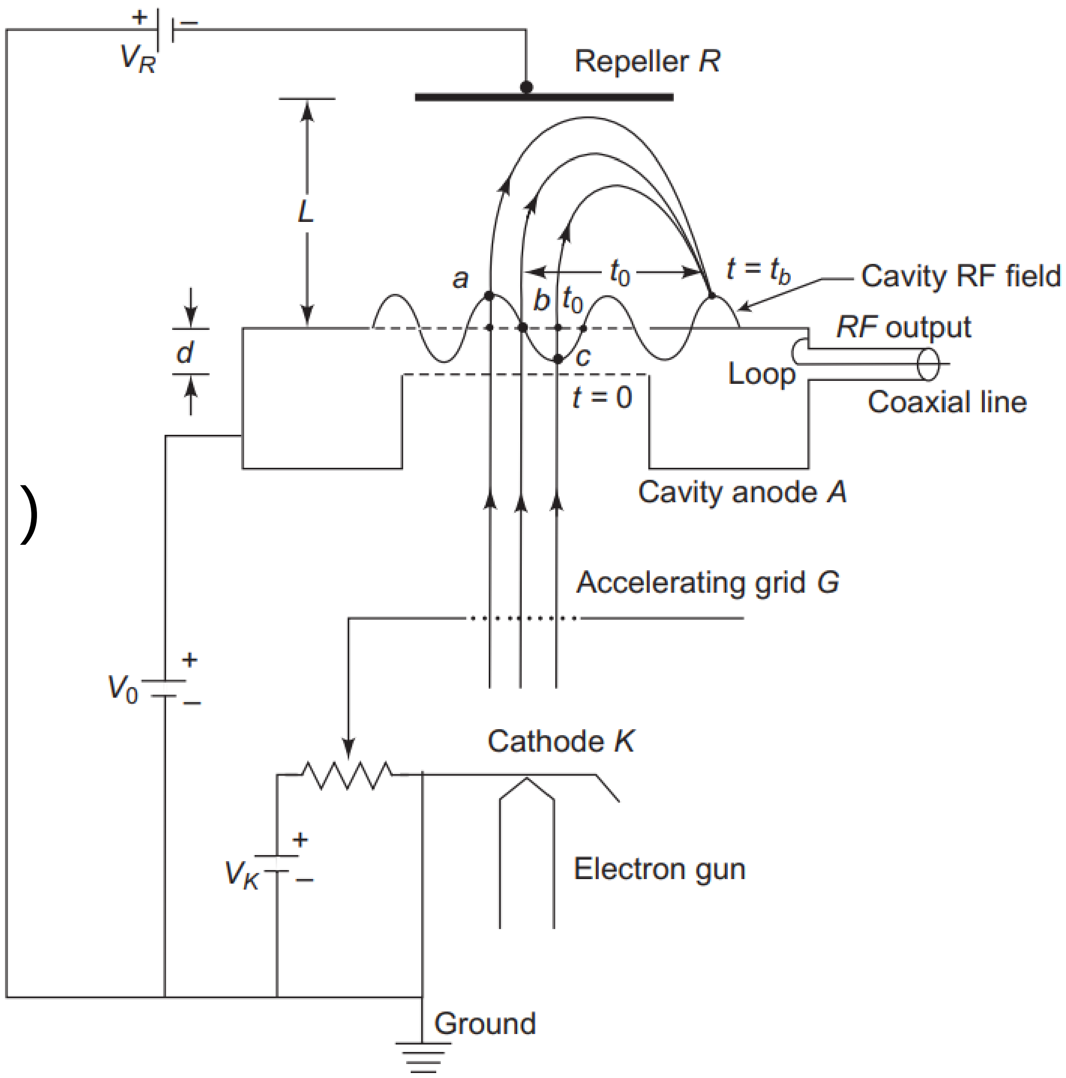

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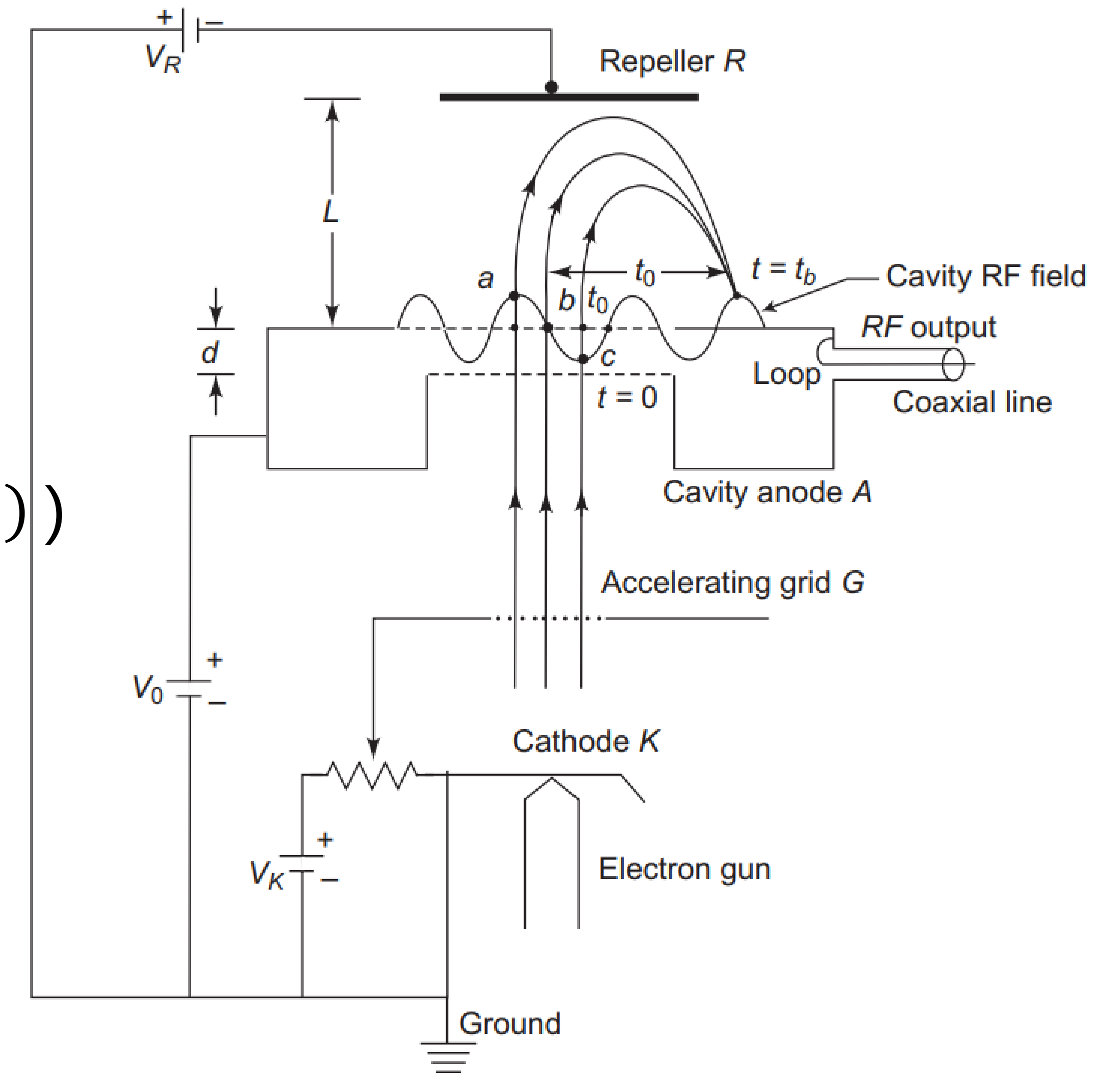
$$= \sqrt{\frac{2eV_0}{m}\left[1 + \frac{V_1\beta_1}{V_0}\sin\frac{\theta_g}{2}\right]}$$

- Depth of modulation $=\beta_1 V_1 / V_0$



6.4 Velocity modulation

$$V_{av} = V_1 \beta_1 \sin \theta_g / 2$$

$$\beta_1 = \frac{\sin\left(\frac{\theta_g}{2}\right)}{\theta_g/2} = \frac{\sin\left(\frac{\omega d}{2u_0}\right)}{\omega d/2u_0}$$

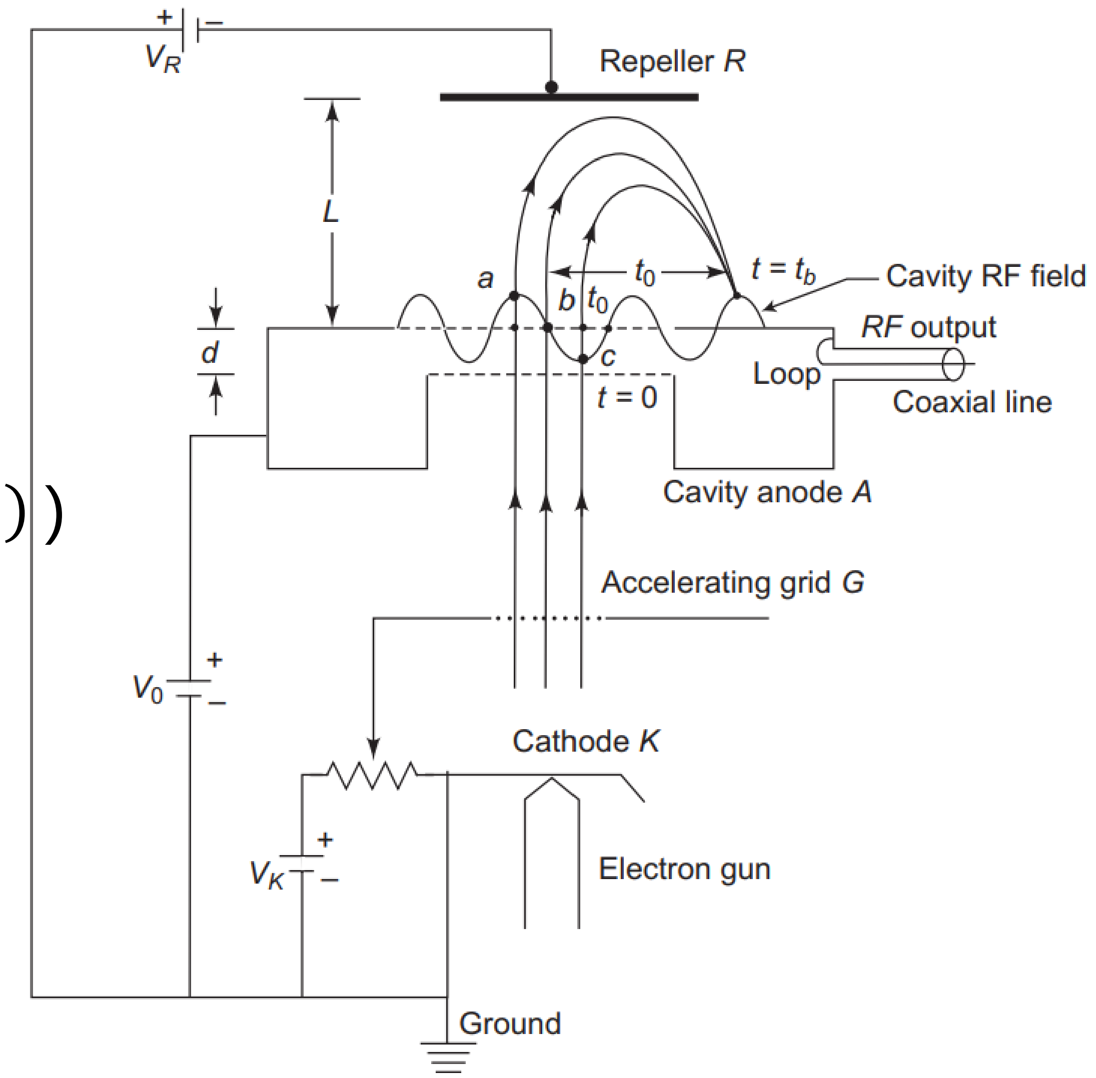
Exit velocity from cavity gap ($\frac{1}{2}mu^2 = e(V_{av} + V_0)$)

$$u(t_g) = \sqrt{[2e(V_0 + V_{av})/m]}$$

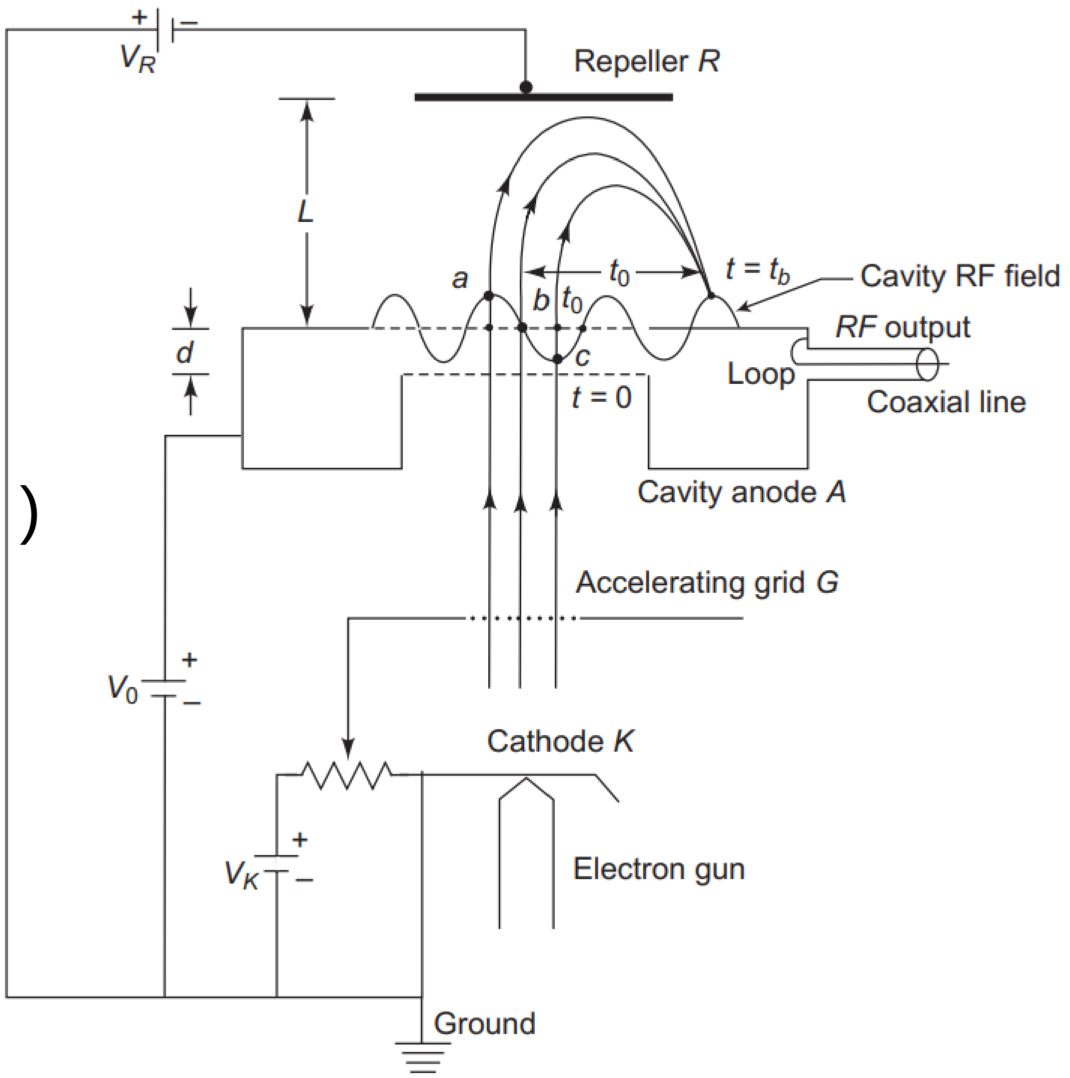
$$= \sqrt{\frac{2eV_0}{m}\left[1 + \frac{V_1\beta_1}{V_0}\sin\frac{\theta_g}{2}\right]}$$

- Depth of modulation $=\beta_1 V_1/V_0$
- If modulation amplitude is small $\left(\frac{\beta_1 V_1}{V_0} \ll 1\right)$,

$$u(t_g) = \sqrt{\frac{2eV_0}{m}}\left[1 + \frac{V_1\beta_1}{V_0}\sin\frac{\theta_g}{2}\right]^{1/2} =$$



6.4 Velocity modulation



$$V_{av} = V_1\beta_1 \sin\theta_g/2$$

$$\beta_1 = \frac{sin\left(\frac{\theta_g}{2}\right)}{\theta_g/2} = \frac{sin\left(\frac{\omega d}{2u_0}\right)}{\omega d/2u_0}$$

Exit velocity from cavity gap ($\frac{1}{2}mu^2 = e(V_{av} + V_0)$)

$$u(t_g) = \sqrt{[2e(V_0 + V_{av})/m]}$$

$$= \sqrt{\frac{2eV_0}{m}\left[1 + \frac{V_1\beta_1}{V_0}\sin\frac{\theta_g}{2}\right]}$$

- Depth of modulation $=\beta_1 V_1/V_0$
- If modulation amplitude is small $\left(\frac{\beta_1 V_1}{V_0} \ll 1\right)$,

$$u(t_g) = \sqrt{\frac{2eV_0}{m}}\left[1 + \frac{V_1\beta_1}{V_0}\sin\frac{\theta_g}{2}\right]^{1/2} = \mathrm{u}_0\left[1 + \frac{V_1\beta_1}{2V_0}\sin\frac{\theta_g}{2}\right] = \mathrm{u}_0\left[1 + \frac{V_1\beta_1}{2V_0}\sin\frac{(\omega t_g - \theta_g)}{2}\right]$$

6.5 Transit time

- Roundtrip time in repeller space
- $t_r = \frac{2\text{velocity}(u)}{\text{acceleration(a)}} = t_0\left[1 + \frac{\beta_1 V_1}{V_0}\sin\left(\omega t_g - \frac{\theta_g}{2}\right)\right]$