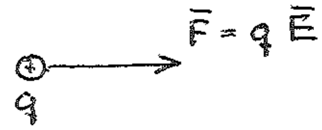
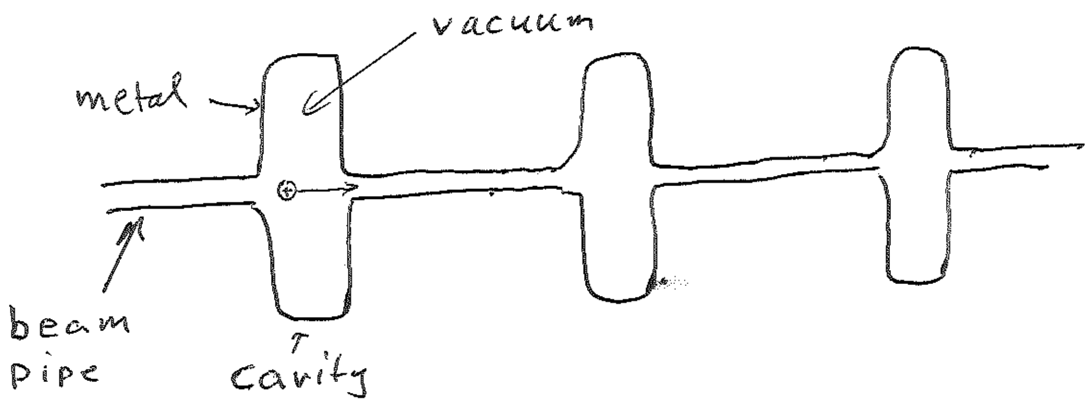
Lecture on Rf-systems NPAS 2017

Particles are accelerated by electric forces!



Electrostatic accelerators can only accelerate up to 30 MeV. For larger energies we need electromagnetic waves!

Ex Let's follow a proton in a linear accelerator



No forces in the beam pipe ⇒ constant speed

Electric field in cavity ⇒ acceleration

Cavities

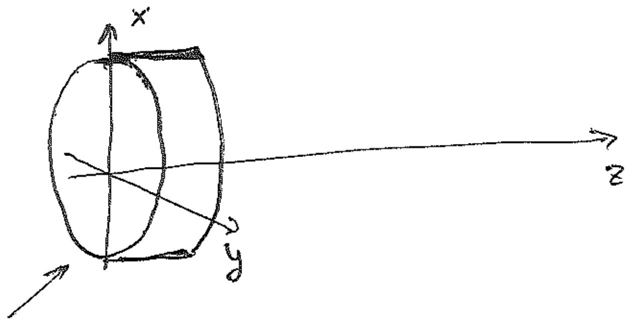
A cavity has resonance frequencies. $f_1, f_2, f_3 \ldots$

To each resonance there is an electromagnetic standing wave. We call such a wave a mode.

We use one of the modes for acceleration of the particles.

Anders Karlsson
EIT

<u>Example</u> The pill-box cavity



Pill-box = circular cylinder

The perfect mode for acceleration is the fundamental mode. It is called TM010.
The electric field of this mode is given by

$$\vec{E}(\rho,t) = E_0 J_0(k\rho) \cos\omega t \cdot \hat{z}$$

where $\rho = \sqrt{x^2+y^2}$

$k = \frac{\omega}{c}$ = wavenumber

$\omega = 2\pi \cdot f$ = angular frequency

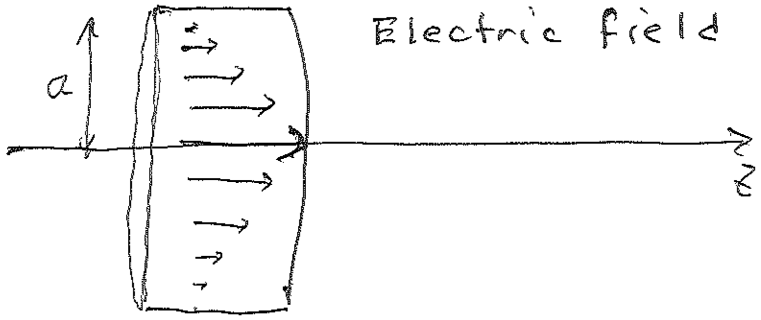
c = speed of light

$J_0(k\rho)$ = Bessel function of order zero.

$\hat{z}$ = unit vector

E_0 = amplitude

$t = 0$



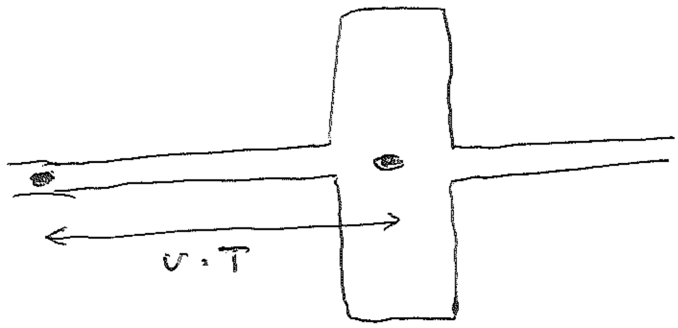
The frequency is $f = \frac{c}{2\pi} \cdot \frac{2.405}{a}$

$a = 10\text{ cm} \Rightarrow f = 1.15\text{ GHz}$

<u>Bunches</u>

The beam of particles must be bunched

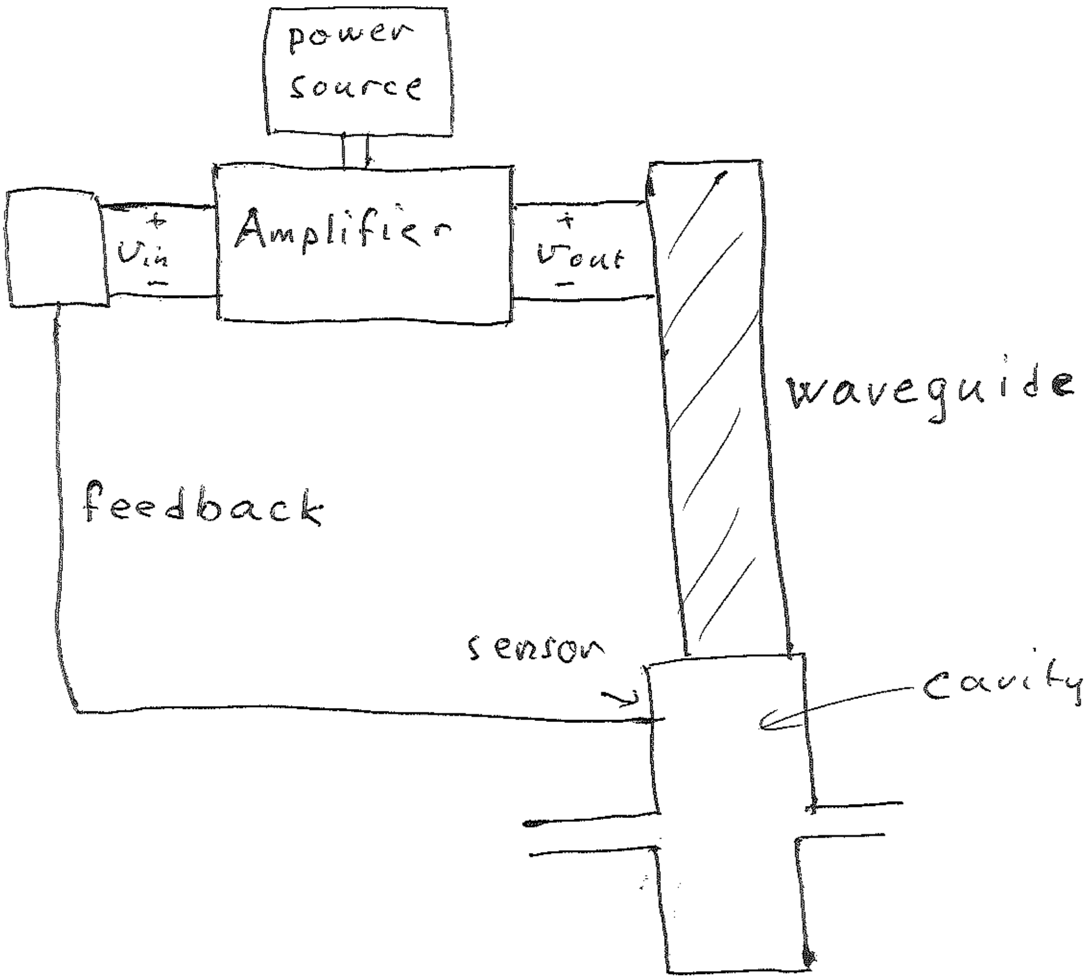
Time between bunches $= T = \frac{1}{f}$



<u>Rf-system</u> (Radio frequency system)

The Rf-system generates the waves and deliver them to the cavity.

Outline of Rf-system



$v_{in}(t) = V_0 \cos(\omega t + \varphi)$ = input voltage

V_0 = amplitude

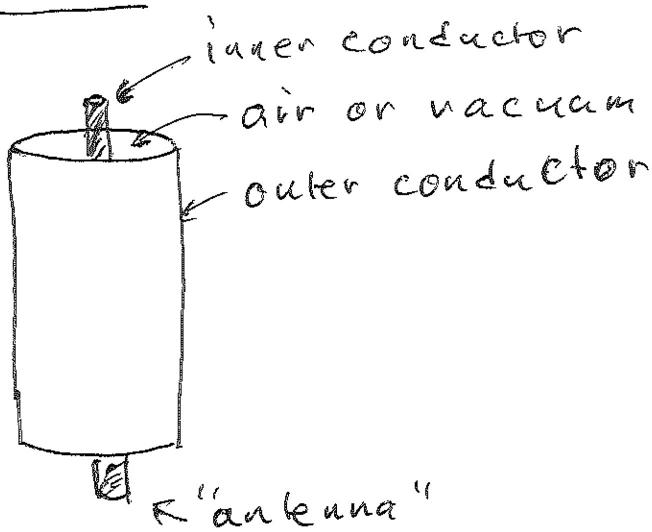
φ = phase angle

$v_{out}(t) = V_1 \cos(\omega t + \varphi)$ = output voltage

gain = $\frac{V_1}{V_0}$

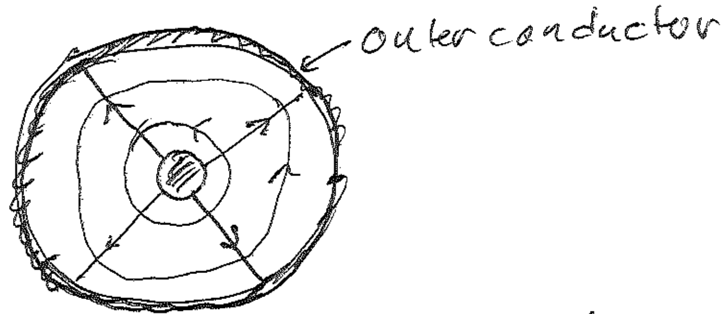
Waveguides

Coaxial



+ All frequencies can propagate
+ All waves propagate with the same speed
− Quite large losses (waves are attenuated)

Ex



$$\bar{E}(\rho, z, t) = E_0 \frac{a}{\rho} \cos(\omega t - kz)\, \hat{\rho}$$

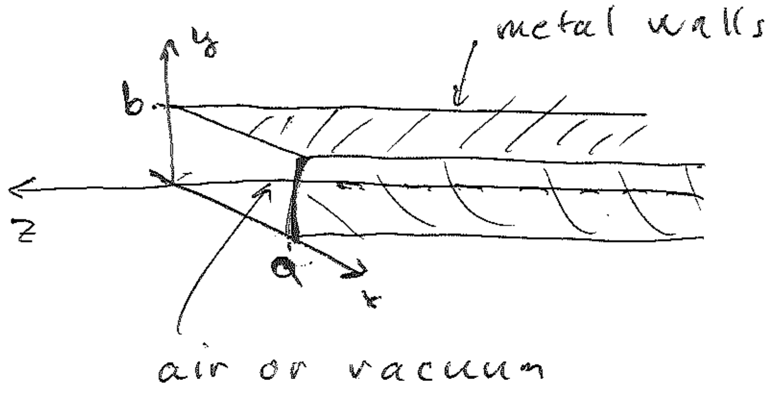
$$\bar{H}(\rho, z, t) = H_0 \frac{a}{\rho} \cos(\omega t - kz)\, \hat{\varphi}$$

$E_0 = \eta_0 H_0$

$\eta_0 = 120\pi$ = wave impedance of vacuum

a = radius of inner conductor

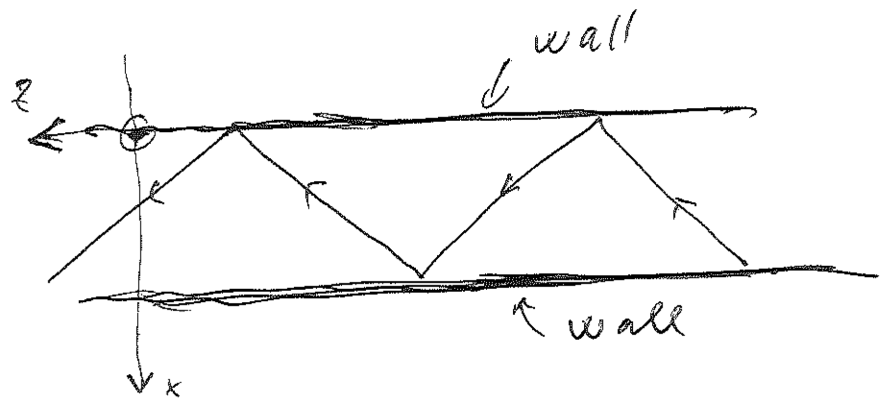
Rectangular



+ low losses

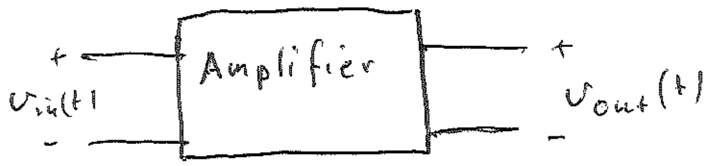
− Only waves with frequencies $> \frac{c}{2a}$ can propagate

− Phase and group speeds are frequency dependent ⇒ dispersion



waves bounce between walls!

The amplifier



$$v_{in}(t) = V_0 \cos(\omega t + \varphi)$$

$$v_{out}(t) = V_1 \cos(\omega t + \varphi)$$

$$\text{Gain} = \frac{V_1}{V_0}$$

$$\text{Gain}|_{dB} = 20 \log\left(\frac{V_1}{V_0}\right)$$

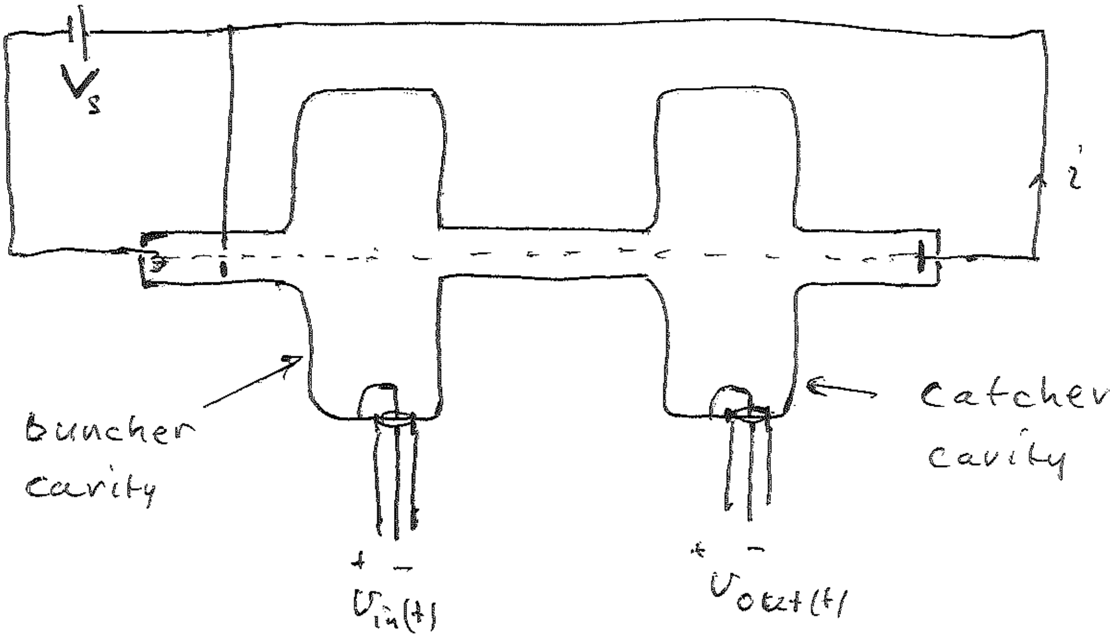
$$\Leftrightarrow \text{Gain}|_{dB} = 10 \log\left(\frac{P_{out}}{P_{in}}\right)$$

P = power

Ex Low gain ⇒ use solid state

Large gain ⇒ larg P_{out} ⇒ use klystron!

The klystron



- Heat filament ⇒ electrons that accelerate to the right. Electric energy → kinetic energy
- Add $v_{in}(t)$ ⇒ Fundamental mode in buncher cavity ⇒ speed modulation of electrons ⇒ bunched beam
- Bunched beam ⇒ excited fundamental mode in catcher cavity. Kinetic energy → EM energy
- Extract power from catcher cavity ⇒ v_{out}

The system again