Istituto Nazionale di Fisica Nucleare

Particle Accelerator Lab

Dottorato di Ricerca

33° CICLO - A.A. 2017/2018

Date	Activity	Coordinator (Tutors)	Notes
12/04/2018 14.00 – 18.00	RF Lab - I	**Luca Piersanti** Fabio Cardelli Alessandro Gallo Marco Bellaveglia	1) Measurement of the R/Q of the accelerating mode of an S-band RF Gun with the bead pull method 2) Experimental characterization in both frequency and time domain of a pulse compressor of the SLED (Stanford Linac Energy Doubler) type
19/04/2018 09.00 – 13.00	RF Lab - II	**Luca Piersanti** Fabio Cardelli Alessandro Gallo Marco Bellaveglia	Group exchange on the 2 activities
10/05/2018 09.00 – 13.00	Magnetic Measurements	**Carlo Ligi** Alessandro Vannozzi Lucia Sabbatini	Characterization of a magnetic quadrupole with a Hall probe Measurement of the electron q/m ratio with a cathodic tube
17/05/2018 09.00 – 13.00	UHV Techniques	**David Alesini** Simone Bini Fara Cioeta	Introduction to the UHV techniques for accelerators Experimental examples with a test chamber
24/05/2018 09.00 – 13.00	Accelerator Controls	**Marco Bellaveglia** **Giampiero Di Pirro**	Introduction to LabView Application examples on simple motor control
31/05/2018 09.00 – 13.00	Beam Diagnostics I	**Angelo Stella**	Bench characterization of Beam Position Monitors
07/06/2018 09.00 – 13.00	Beam Diagnostics II	**Enrica Chiadroni** Vladimir Shpakov Marco Marongiu	Measurement of the emittance of an optical beam
14/06/2018 09.00 – 13.00	Beam Measurements @ SPARCLAB	**Riccardo Pompili** Marco Bellaveglia	Experimental measurements on the SPARC_LAB beam

MEASUREMENTS LAB

position & charge monitors

- summary of tests & measurements

- Ref & bibliografy on beam diagnostics

Beam Position Monitors

•BPMs are the most common non destructive diagnostics devices installed in nearly any accelerators.

•The principle is to measure the charges induced by the em field of the particle beam on a pickups installed in the vacuum chamber.

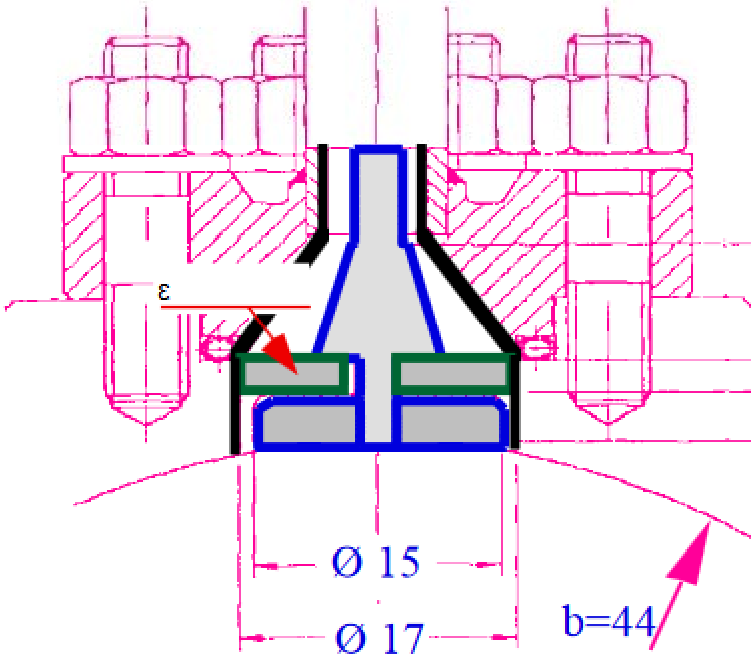
- •Particle bunches induce a voltage on each electrode
- •By comparing signals from opposite pickups, the transverse beam position is calculated.

•The measurement of beam position relies on processing the information from pick-up electrodes located in the beam pipe. Different pick-up families can be commonly employed:

- Capacitive– ('button' and 'shoe-box' pick-ups)
- Electromagnetic – stripline couplers
- Resonant cavity
- Magnetic
- Resistive

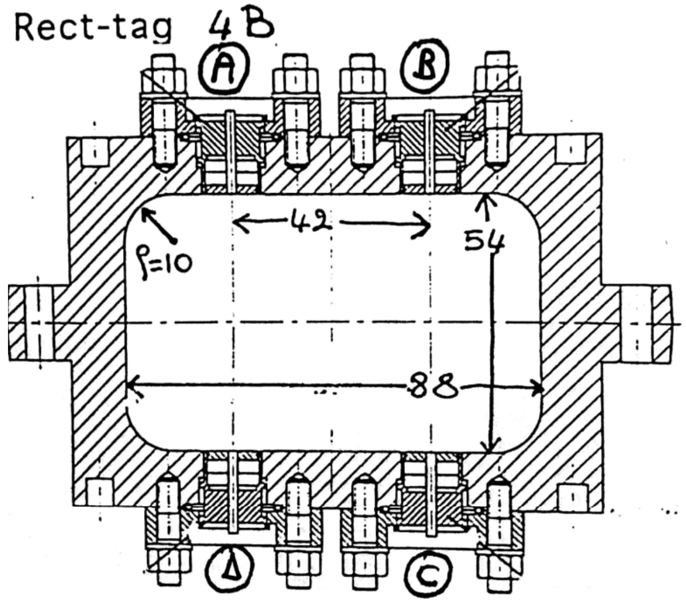
•The transfer impedance, defined as the ratio of the pick-up output voltage (V) to the beam current (I_B), can be used as a figure of merit for any pickup. It describes the effect of the beam on the pick-up voltage and it is dependent on frequency and on geometrical factors

• capacitive pick-ups



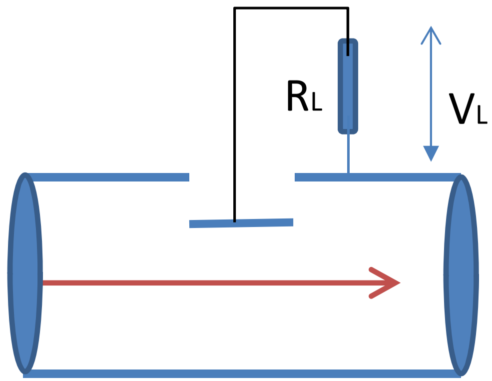
$$x = k_x \frac{(V_b + V_c) - (V_a + V_d)}{(V_a + V_b) + (V_c + V_d)}$$

$$y = k_y \frac{(V_a + V_b) - (V_c + V_d)}{(V_a + V_b) + (V_c + V_d)}$$



- Capacitive type=derivative response,
- low coupling impedance,
- low sensitivity
- used in storage rings.

a capacitive pick-up consists of a plate or a ring inserted in the beam pipe. The capacitance C, is determined by the distance of the plate with respect to the beam pipe

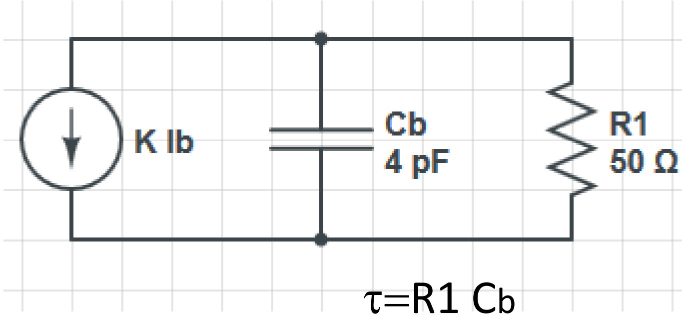


• Button pick-ups

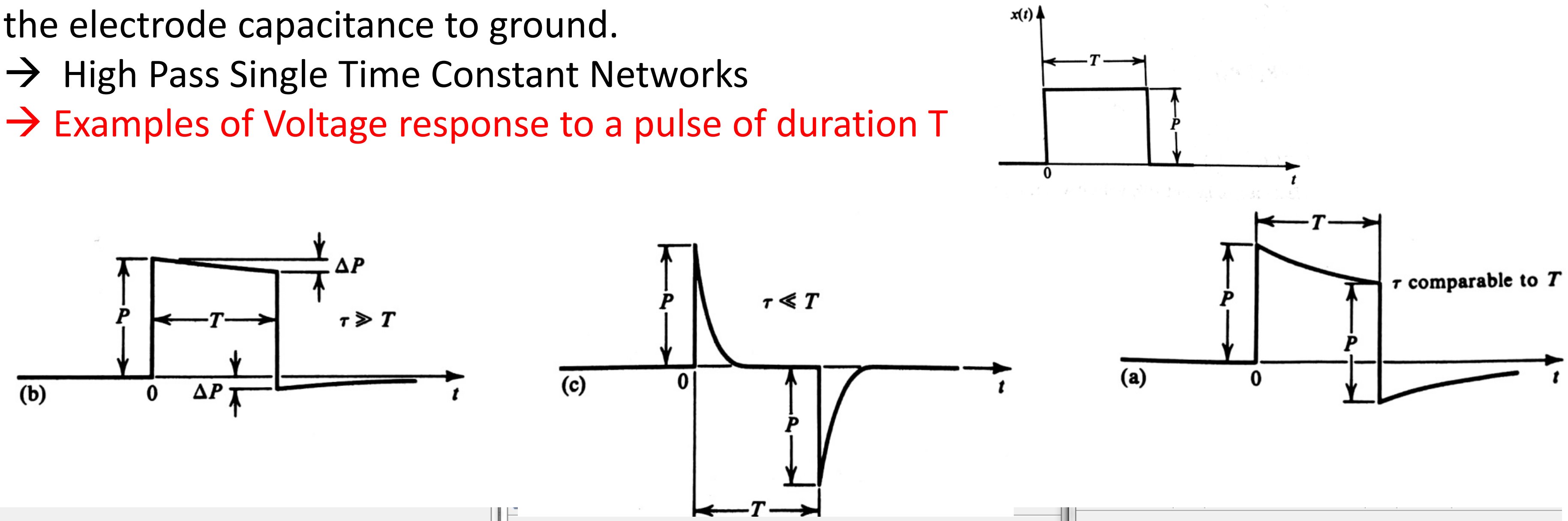
The usual equivalent circuit representation of the ordinary button pickup is a current generator of the same value of the beam image current intercepted shunted by the electrode capacitance to ground.

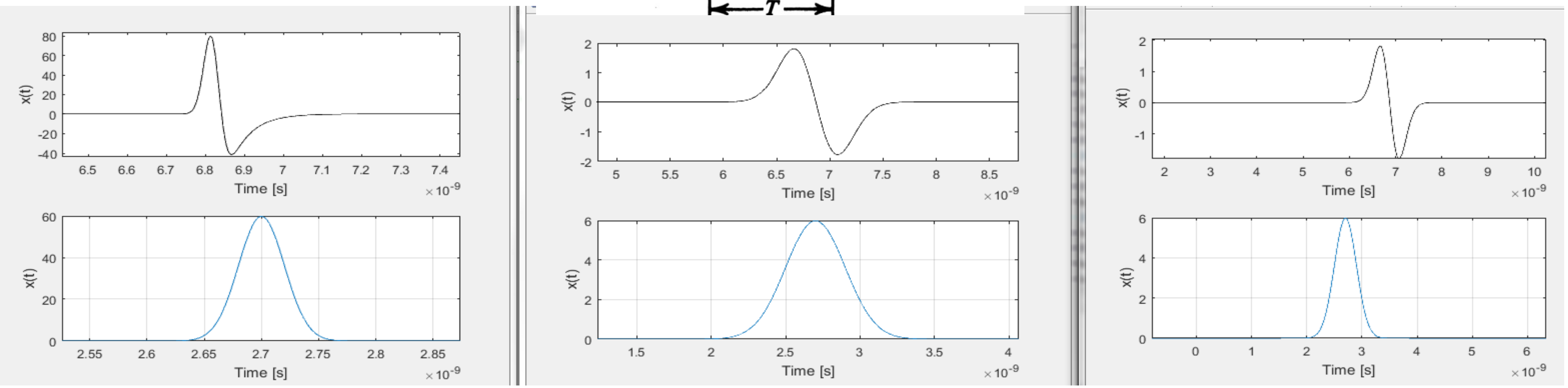
→ High Pass Single Time Constant Networks

→ Examples of Voltage response to a pulse of duration T



τ=R1 Cb





•"button" BPMs

Eq. Circuit model

•Transfer impedance / Frequency Response

Here $V(\omega)$ and $I(\omega)$ are the spectral densities of the load voltage $V_0(t)$ and beam current $i(t)$, respectively. Then, according to the definition, the transfer (signal) impedance is given by:

$$Z_b(\omega) \equiv \frac{V(\omega)}{I(\omega)} = R_0 \frac{j\omega r^2 / 2bc}{1 + j\omega R_0 C_b} . \qquad \text{(A.6)}$$

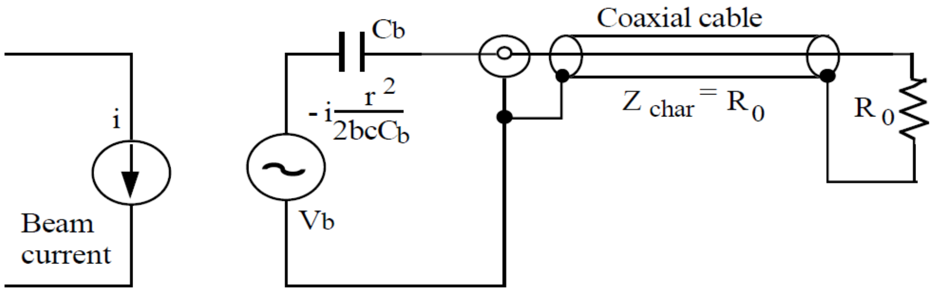
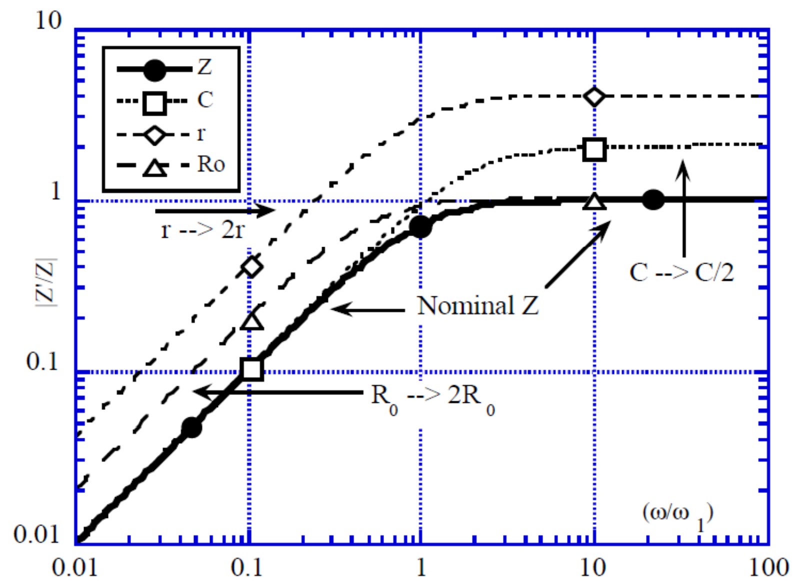


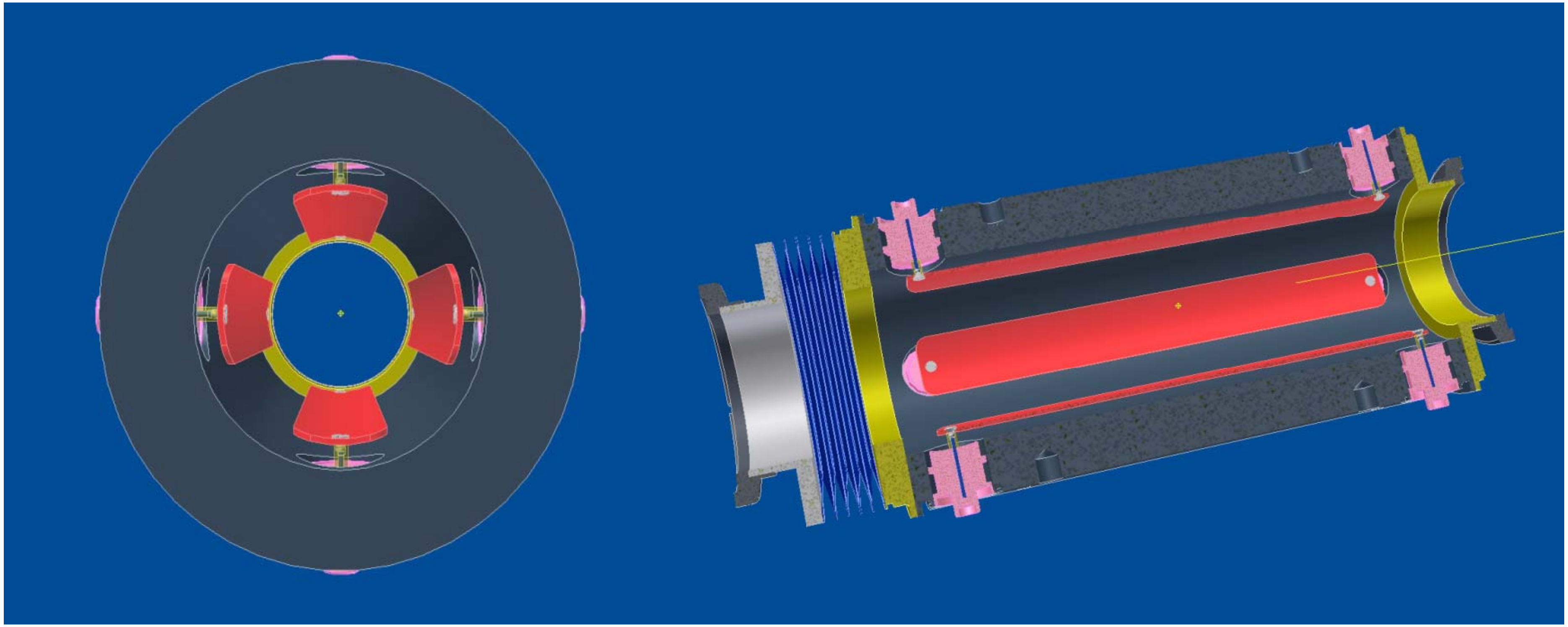
Fig. A.3 - Terminated button equivalent circuit.

RC~200ps



•“stripline” BPMs

A stripline BPM has four electrodes placed symmetrically around the vacuum chamber and parallel to the chamber axis. One end of the electrode is brought out and connected to a load, the other can be shorted or open circuited or matched to 50ohm.
A displaced beam produces non-equal current distributions on stripline electrodes.
Comparing these signals allows to measure the bunch transverse position.



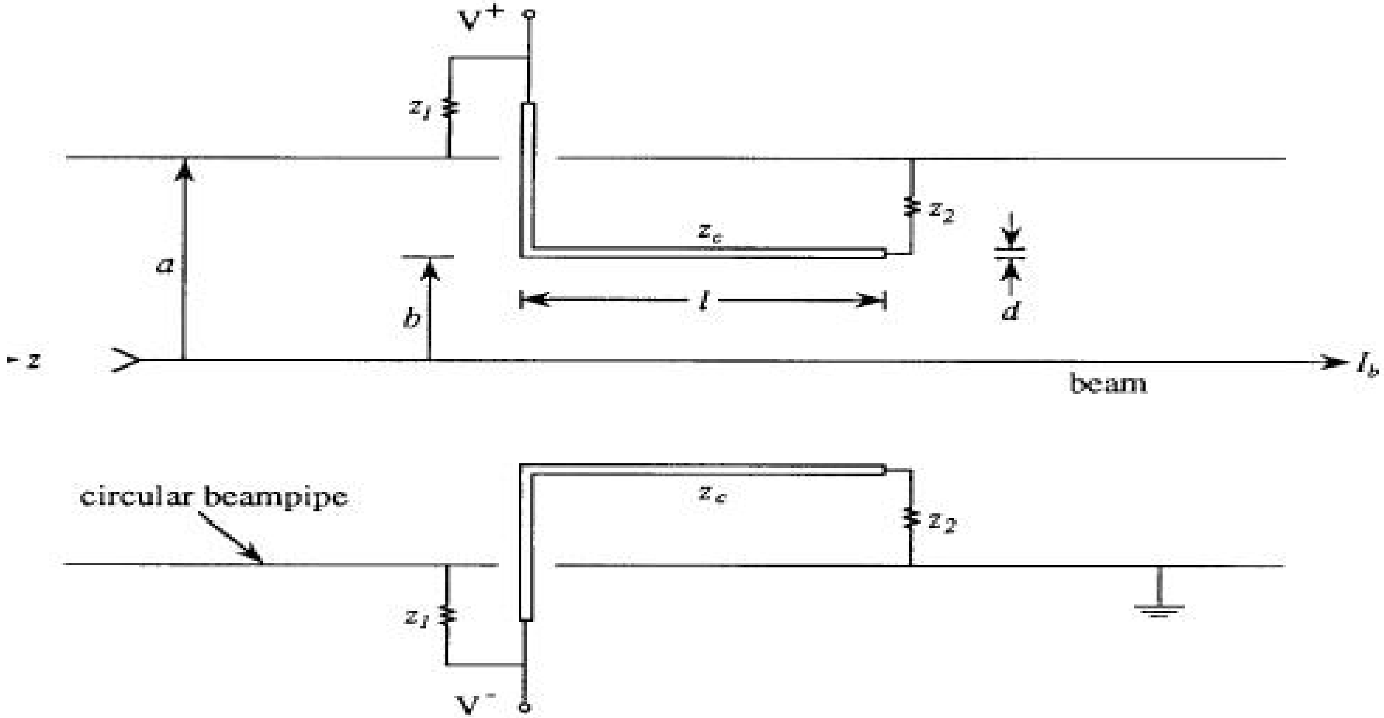


Fig. 1. General wireline pickup BPM.

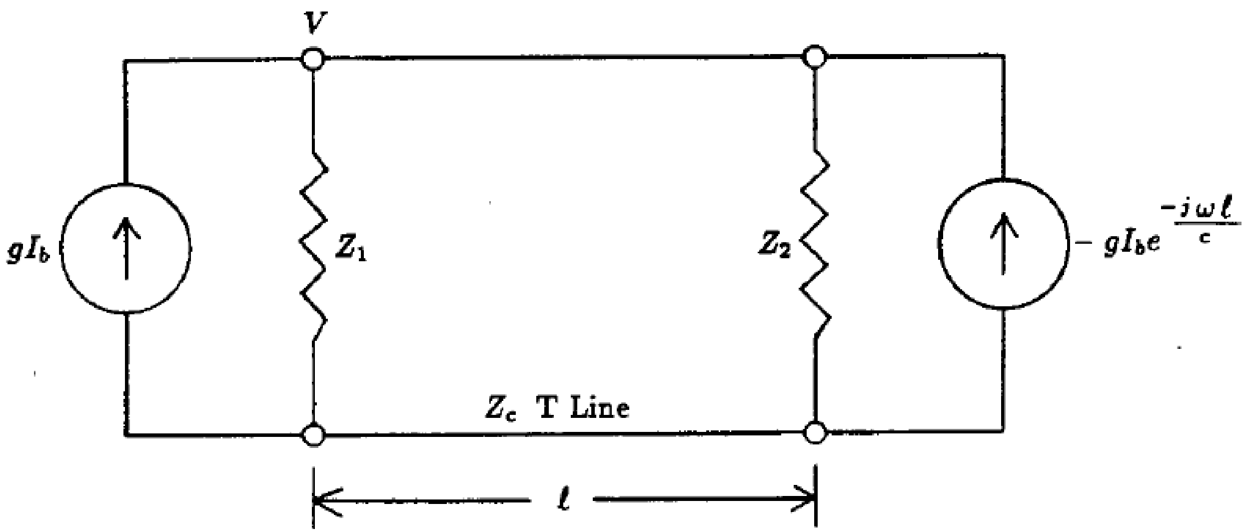


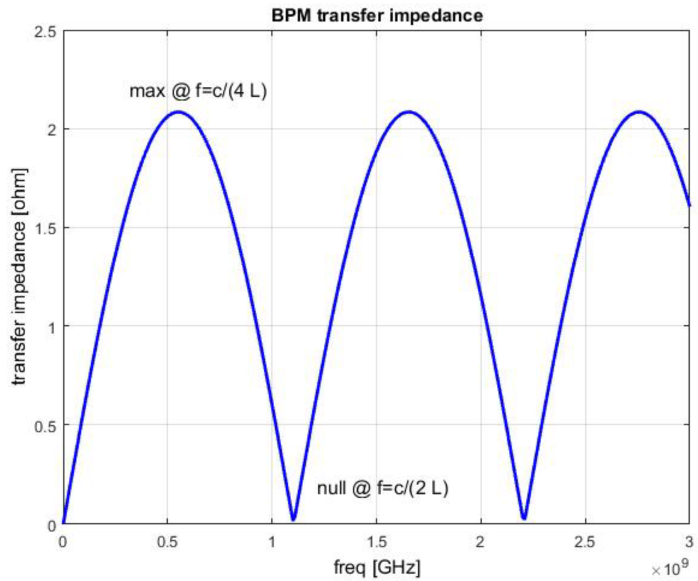
Figure 2 Equivalent circuit for general wireline pickup.

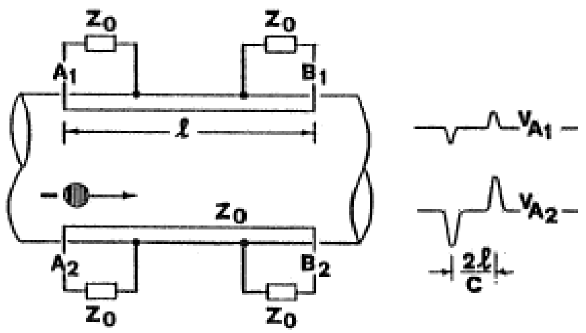
Beam currents interact with pickups at the upstream and downstream ends of the strip (TEM modes)

Fig. Credit: W.Barry, NIM A301 (1991)

•“stripline” BPMs

•each stripline is an electrode forming a transmission line of characteristic impedance Z0 with the vacuum pipe,
•Z0=50ohm by a suitable choice of the ratio between the strip
and distance from the pipe
•Electrode termination as shortcircuit/open circuit/Z0
    •Matched striplines BPM are directional: signal at the up-
    port
•Doublet of pulses of opposing polarity and separated by 2*l*/*c*
•Maximum response at frequency *c/4l* and zero at *c/2l*
•*Position sensitivity x~(R/2)*delta/sigma*





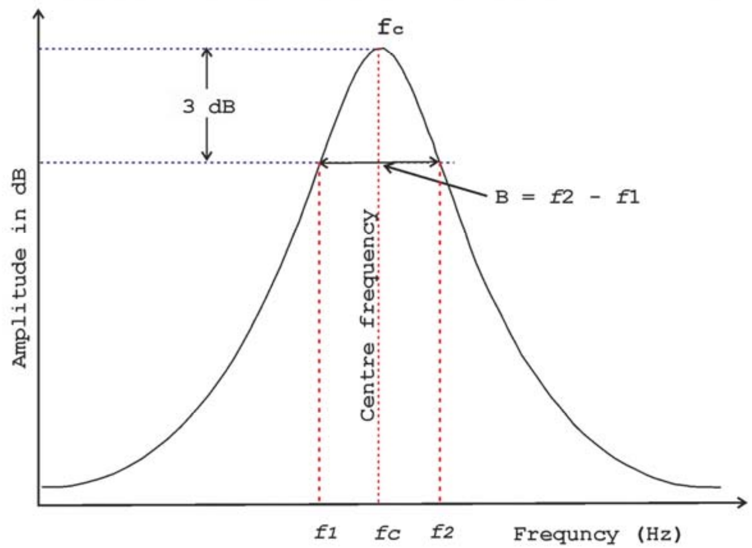
$$Z_c(j\omega) \equiv \frac{V(j\omega)}{I_b(j\omega)} \approx Z_0\left(\frac{\alpha}{2\pi}\right)\sin\left(\frac{\omega l}{c}\right)e^{j\left(\frac{\pi}{2}-\frac{\omega l}{c}\right)}$$

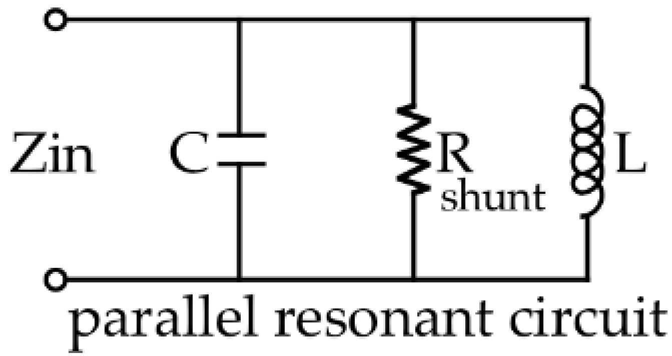
$$v(t) = \frac{Z_0}{2}\left(\frac{\alpha}{2\pi}\right)\left[i_b(t) - i_b\left(t - \frac{2l}{c}\right)\right]$$

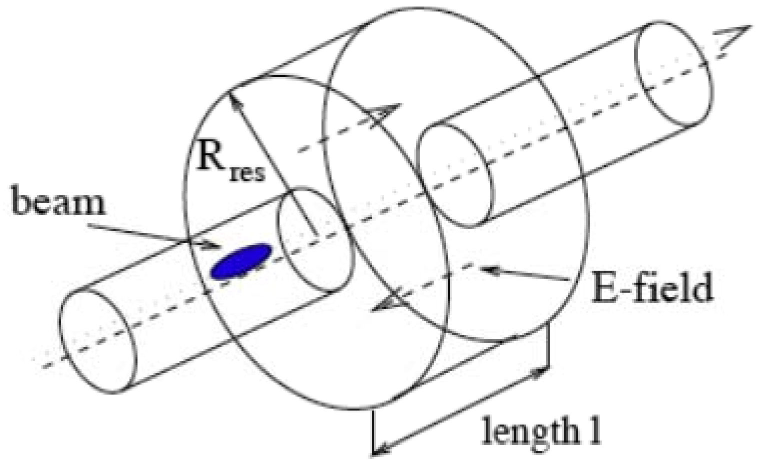
Fig. Credit: M.Serio LNF-89/021

•"cavity" BPMs

Cavity BPMs use dipoles modes of em field excitations. When electron beam passes the cavity , various resonant em modes are excited, by selecting modes sensitive to beam position it is possible to measure beam offset







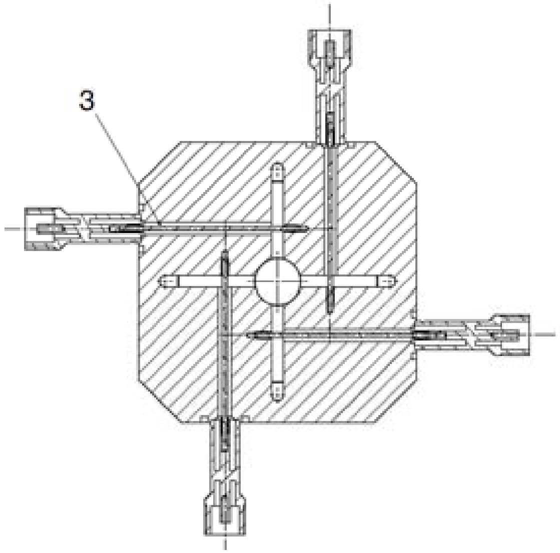
For BPM, TM mode is used.

Monopole Mode TM010,usually used for accelerating cavities, gives the beam current reference.

Dipole mode TM110 is used for position detection: when the beam passes the cavity with an offset, the amplitude of the excited signal is proportional to the beam offset

Tomeasure beam position it is critical to read out the dipole mode and to reject other modes

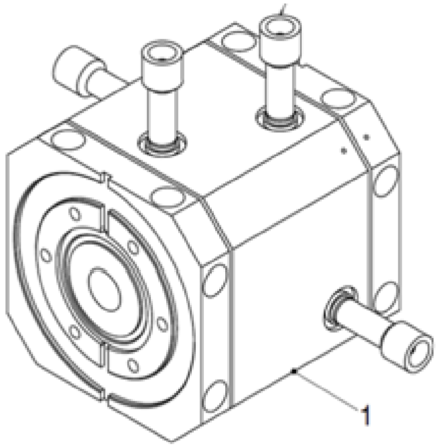
SwissFEL BPM16 Pickup

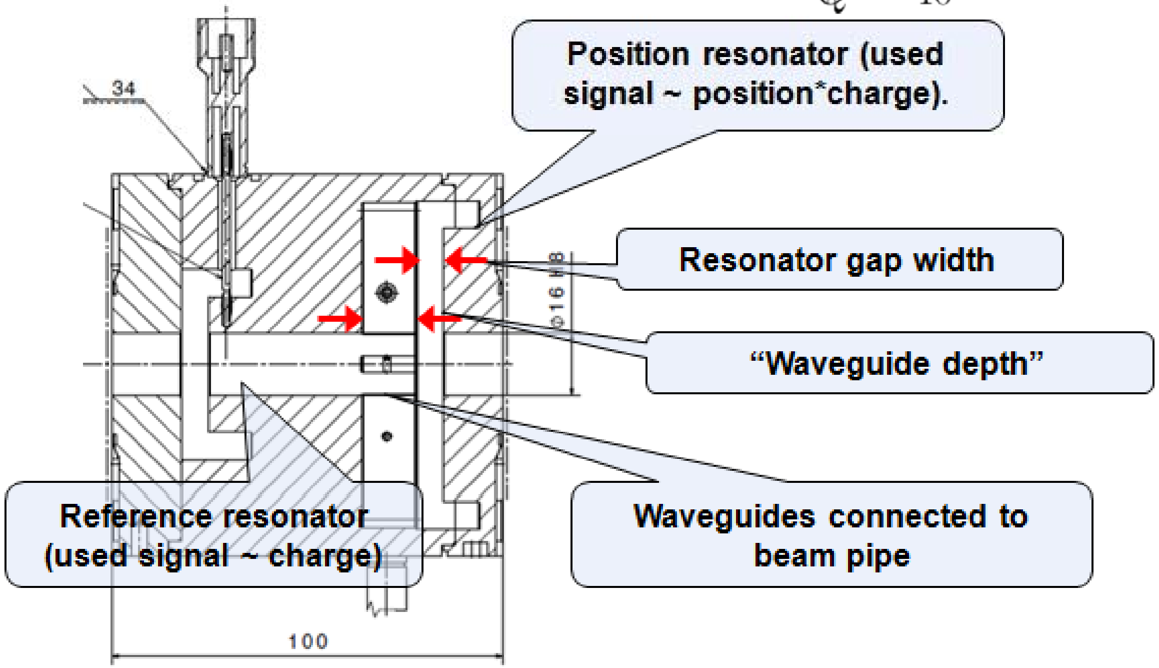


- Based on E-XFEL/SACLA design
- Optimized for low charge & low production costs.

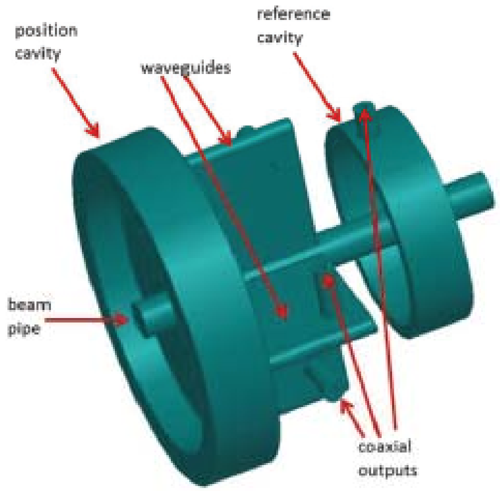
$$f_{res} = 3.284GHz$$

$$Q = 40$$





Ref: F.Marcellini, IBIC2012



The pickup consists of two cavities, the working modes are TM110 (dipole, on full period of azimutal variation) for the position cavity and TM010 (monopoleno azimutal variation) for the reference cavity. When the beam crosses the two cavity gaps it induces signal proportional to the product of charge and position offset in the position cavity , and to charge only in the reference cavity.
The beam position is then obtained by the ratio of the two signal amplitudes, available by means of dedicated couplers.
The position cavity has four rectangulare waveguides that couple to the dipole mode while rejecting the monopole mode (under cutoff).
The waveguides are connected to the cavity volume through slots placed 90° apart from each other on one cavity side wall. Each waveguide has a transition to a coaxial line which ends with a type N-connector output.
In the reference cavity the signal is coupled out through a coaxial line where the inner conductor passes through the cavity.

Figure 4: SwissFEL undulator prototype: pictures of the 3 parts composing the pickup body and final assembly after brazing.

Ref:
F.Marcellini et al, Proc. IBIC2012
DESIGN OF CAVITY BPM PICKUPS FOR SWISSFEL

Cavity BPMs

- When a beam passes through the cavity, it excites electro-magnetic field oscillations in the cavity. If the beam is off-centered, dipole modes TM110 is excited. The larger the offset of the beam, the stronger is the excitation
- noise modes are rejected due to the cut off frequency of the wave guides.

$$Vout = U_{out} \cdot e^{-\frac{t}{\tau}} \cdot \sin(2\pi f_R t + \varphi)$$

$f_R = resonance\ frequency$

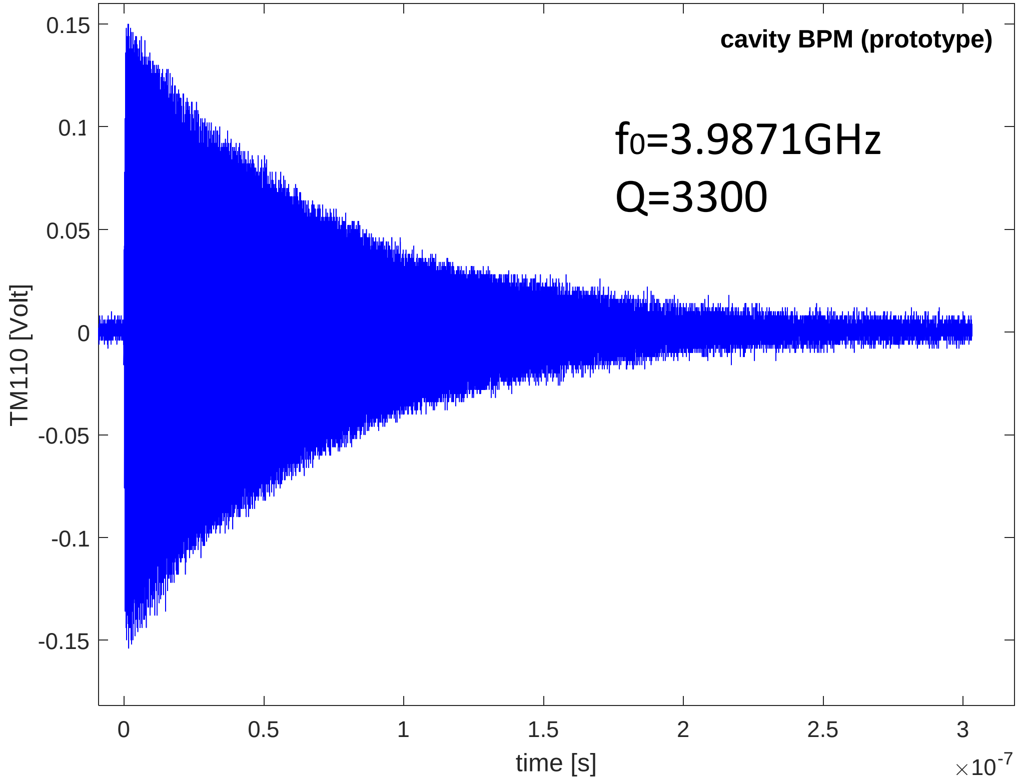
$\tau = \frac{Q_L}{\pi f_s}, decay\ time$

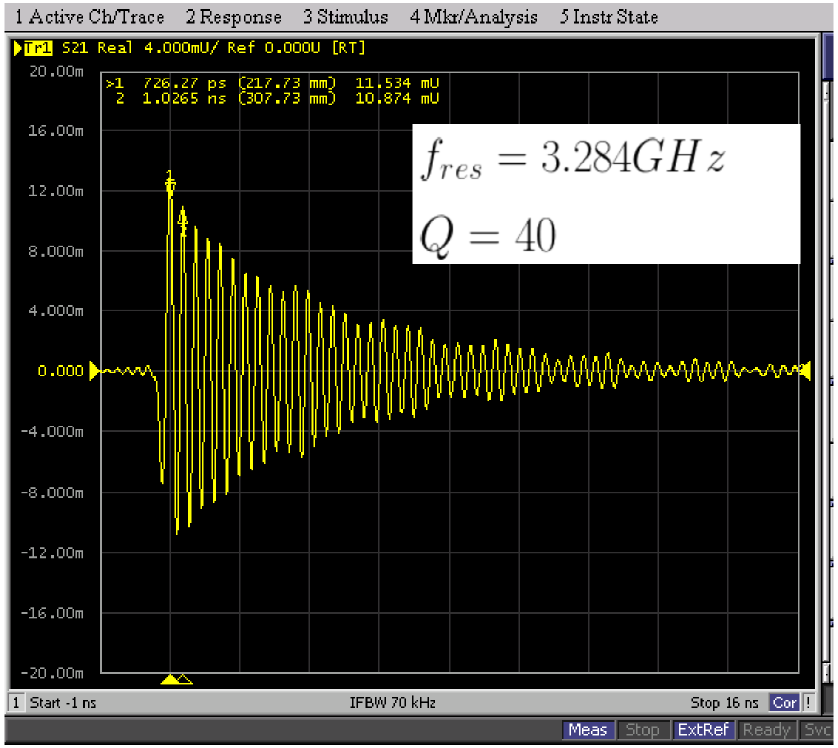
$Q_L =, loaded\ quality\ factor$

$BW = \frac{f_S}{Q_L}, bandwidth$

$U_{out} \propto beam\ offset$

Cavity BPMs output Examples





Current Transformer

- The beam intensity is usually measured by means of a beam current transformer . In such a device the beam can be considered as the primary, one-turn winding of a transformer, with its equivalent current transformed to the secondary winding output.
- It relies on a toroid made of ferromagnetic material to capture the magnetic field, passing it through an n-turn secondary winding loaded with a resistance RL. A beam current IB passing through the toroid induces a current IO = IB/n in the secondary n-turn winding. This current is converted into an output voltage VO = IO × RL

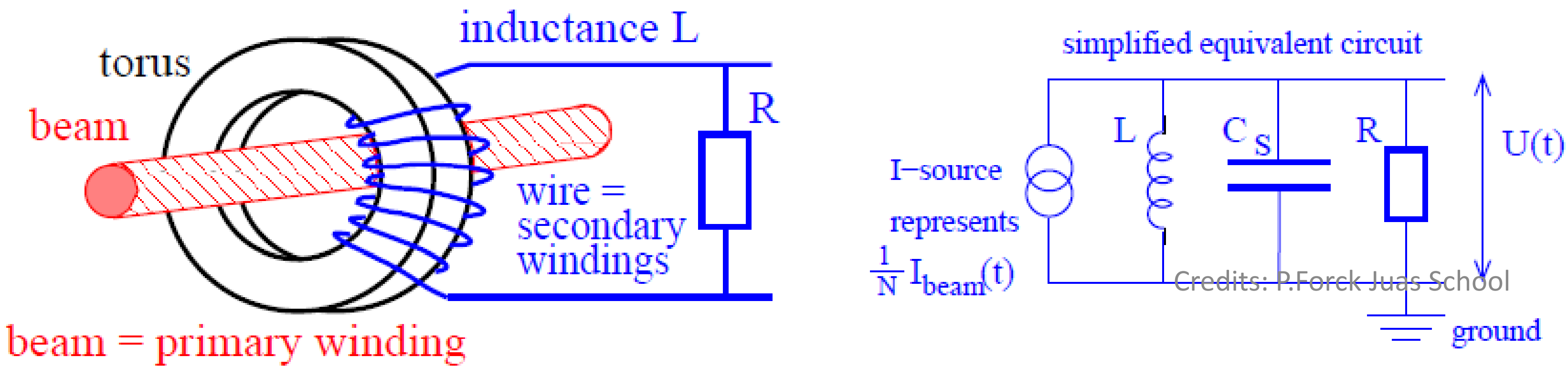


Figure 2.4: Scheme of a current transformer built as a ring-core (torus) around the beam (left) and the simplified equivalent circuit (right).

Fig. Credits: P.Forck Juas School

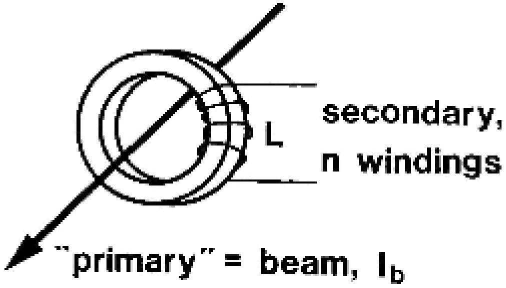
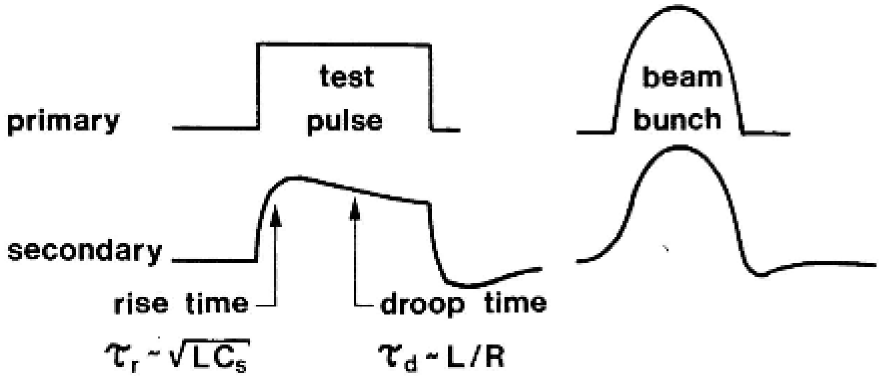


Fig. 1 Principle of the BT.



Ref: H.Koziol, Beam Diagnostic CERN School

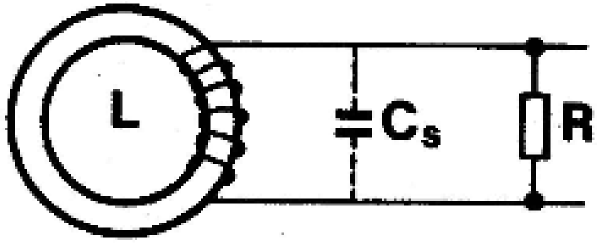
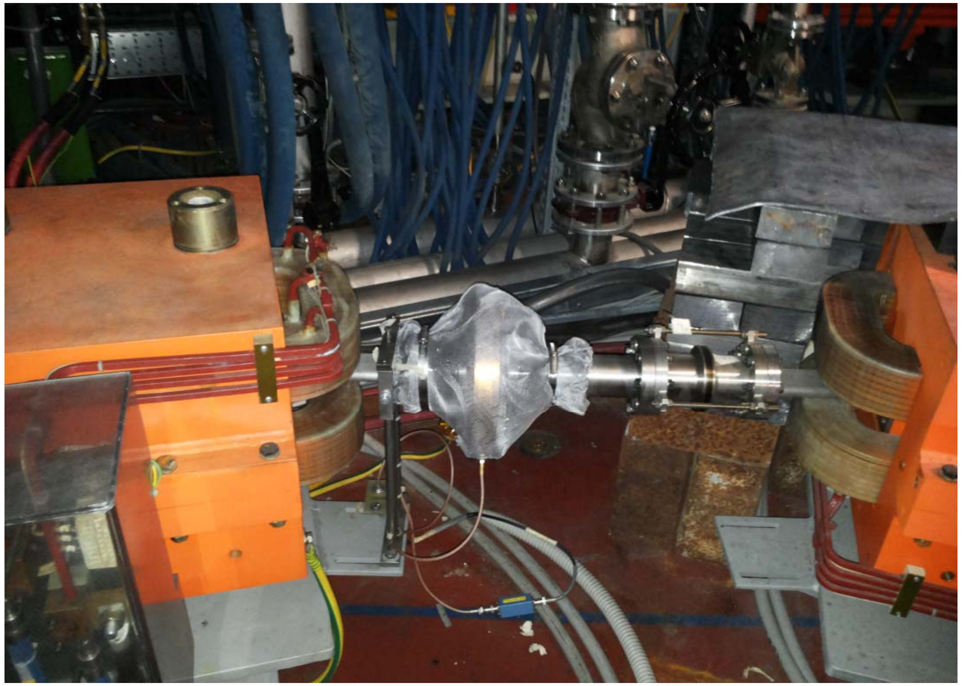


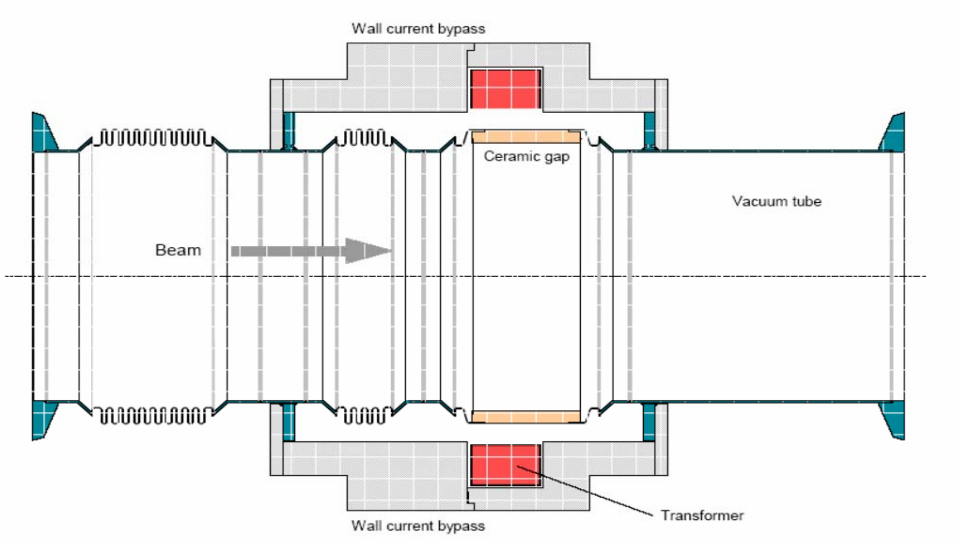
Fig. 3 Real BT with stray-capacity C_S and termination R.

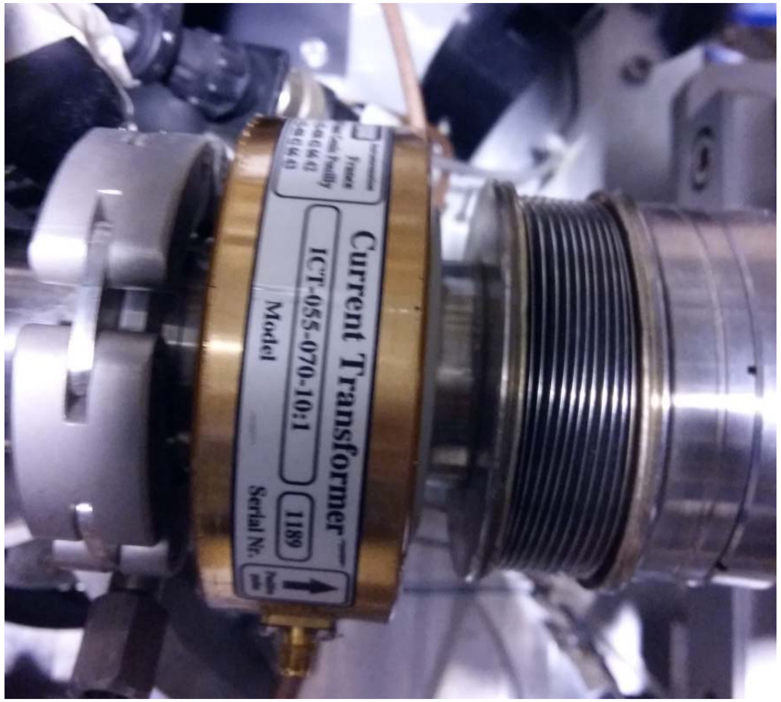
A perfect ICT would reproduce the temporal distribution of the beam current shape without distortion and with amplitudes Vout=Ibeam*Rl/n.
Each real beam current transformer has a limited bandwidth, which can be characterized by the low and high cut-off frequencies.

ICT : Installation Examples @ LNF



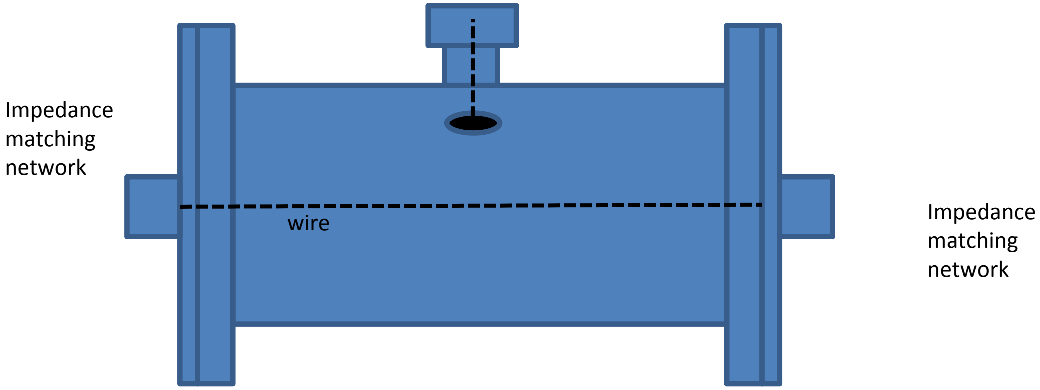
The transformer must be placed over a ceramic gap in the vacuum chamber in order to interact with the magnetic field of the beam it.
A thin metallic coating of the ceramic is required to keep the impedance seen by the beam as low as possible at the high frequency. The external metallic screen is placed externally to keep the vacuum chamber continuity, to prevent charge accumulation and avoid external electromagnetic interference to other accelerator components.



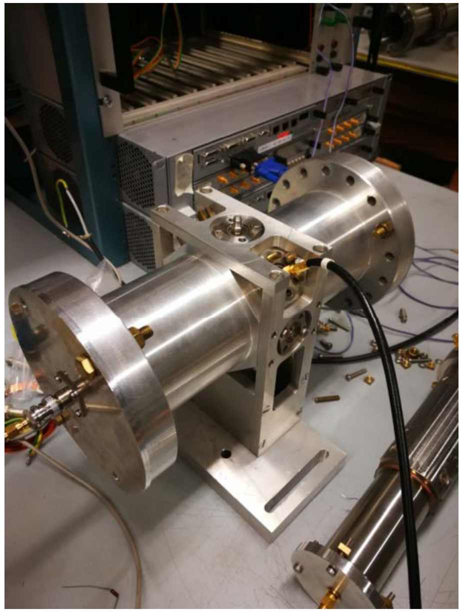


BPM: Bench setup

Description of Measurement setup



A copper rod has been placed inside the BPM block, forming the inner conductor in a coaxial line system having characteristic impedance Z0. Two resistive networks at both ends of the vacuum chamber section allow impedance matching with 50ohm equipment to avoid reflection inside the coaxial structure



Laboratory Ex. 1: BPMs (time domain)

- For this exercise the following is provided:
  - 3 BPM assembly: (button/stripline/cavity)+ antenna+end caps
  - Pulse generator module, oscilloscope

- preparation: generator settings to simulate the beam field in the time domain
- Record, plots and compare the outputs from each pickup
- Test: long coaxial cable effects
- Test: derivative output for longer beam pulses
- Measurement: Frf , Q for Cavity BPM
- Measurement: stripline length

Lab Activity Ex. 2: BPMs (freq domain)

- For this exercise the following is provided:
  - 3 BPM assembly: (button/stripline/cavity)+ antenna+end caps
  - Network Analyzer

- preparation: N/A calibration
- Record, plots and compare the pickups frequency response (300KHz-3GHz)
- Measurement: stripline null frequency and compare with c/2l
- Measurement: Frf dipole mode, Q for dipole mode. Compare with datasheet
- Measurement: button BPM lower cut-off frequency and compare with analytical formula

Lab Activity Ex. 3: ICT

- For this exercise the following is provided:
  - ICT equipped with a single turn loop closed on 50ohm:
  - Network Analyzer, oscilloscope
  - Variable pulse generator module

- preparation: N/A calibration – set pulse module to simulate beam signal
- Measurement: Record time domain ICT output vs time and compare with input signal
- Measurement: compare charge signal from ICT vs charge signal generated by the module, Q evaluation
- Measurement: ICT frequency response

ICT Measurement Setup