CAVITY BPM FOR CALIFES

Claire Simon, Michel Luong,
D. Bogard, P. Contrepois, P. Girardot, J. Novo

CEA/Saclay/IRFU

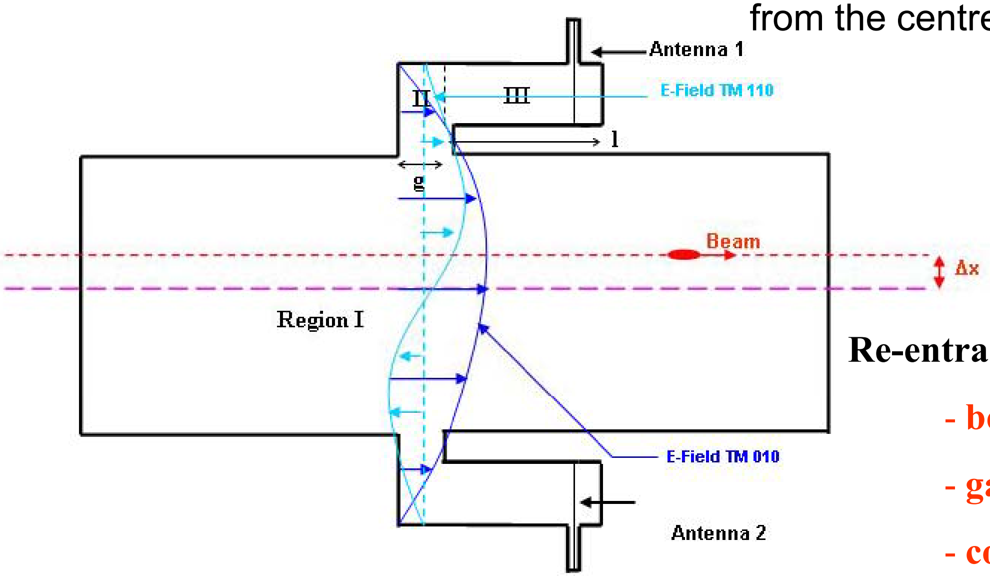
CTF3 Meeting – 22th January 2008

Re-entrant Cavity BPM

- Coaxial re-entrant cavity has been chosen for the beam orbit measurement because of its mechanical simplicity and excellent resolution (concept from CERN).

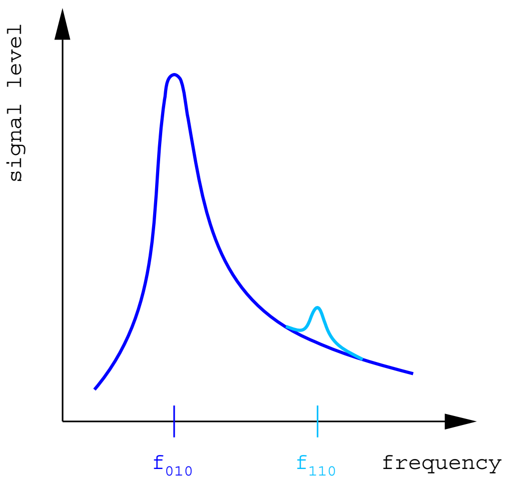
- The re-entrant BPM is composed of a mechanical structure with four orthogonal feedthroughs (or antennas).

- Passing through the cavity, the beam excites some electromagnetic fields (resonant modes)
  - two main modes :
    - monopole mode (proportional to beam intensity and does not depend on the beam position : normalization)
    - dipole mode (proportional to the distance of the beam from the centre axis of the monitor)



Re-entrant Cavity :

- beam pipe (I),
- gap (II),
- coaxial cylinder (III)

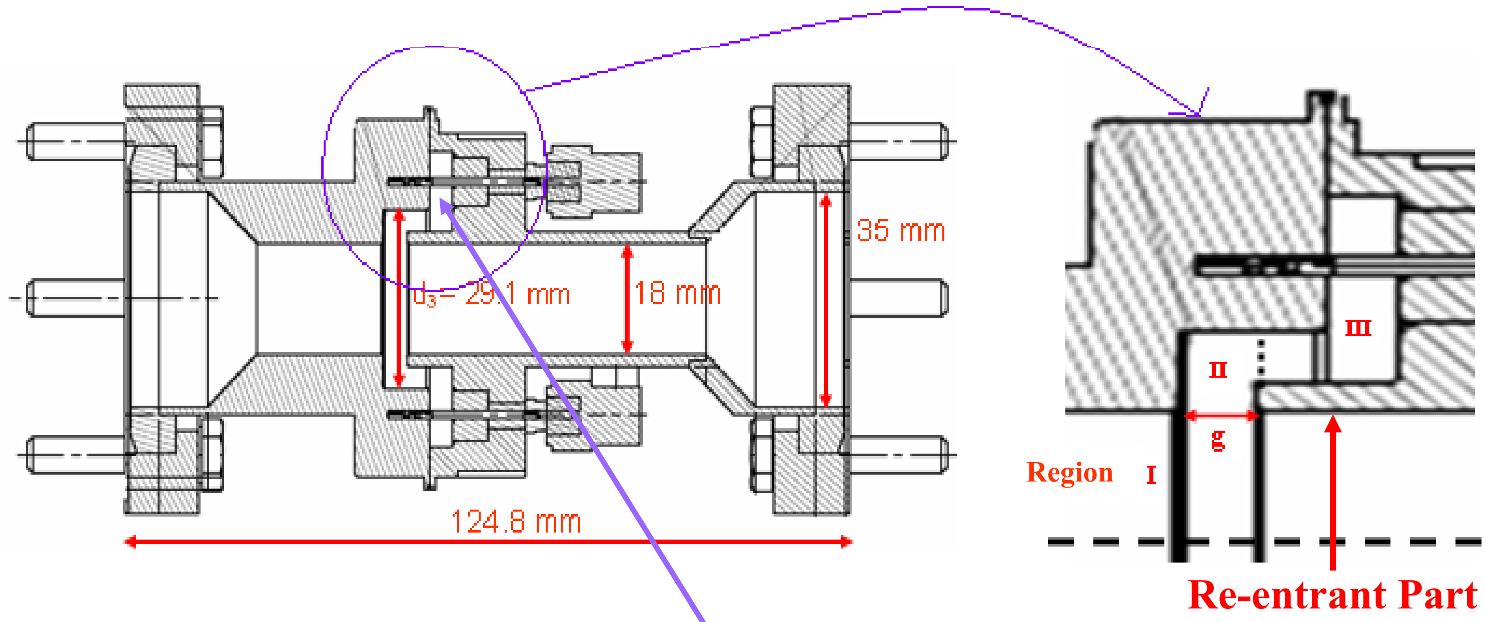


Re-entrant Cavity BPM CALIFES (1)

- It is arranged around the beam tube and forms a coaxial line which is short circuited at one end.

- The cavity is fabricated with titanium and is as compact as possible :

~125 mm length and 18 mm aperture
4 mm gap



Bent coaxial cylinder to separate the main RF modes (monopole and dipole)

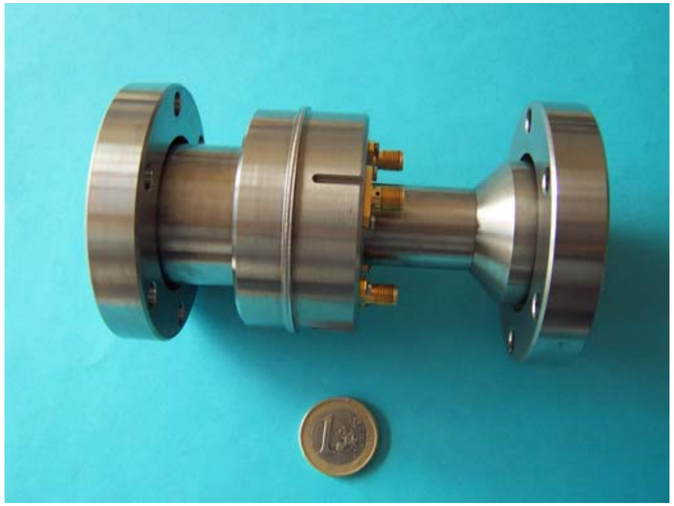
Re-entrant Cavity BPM CALIFES (2)

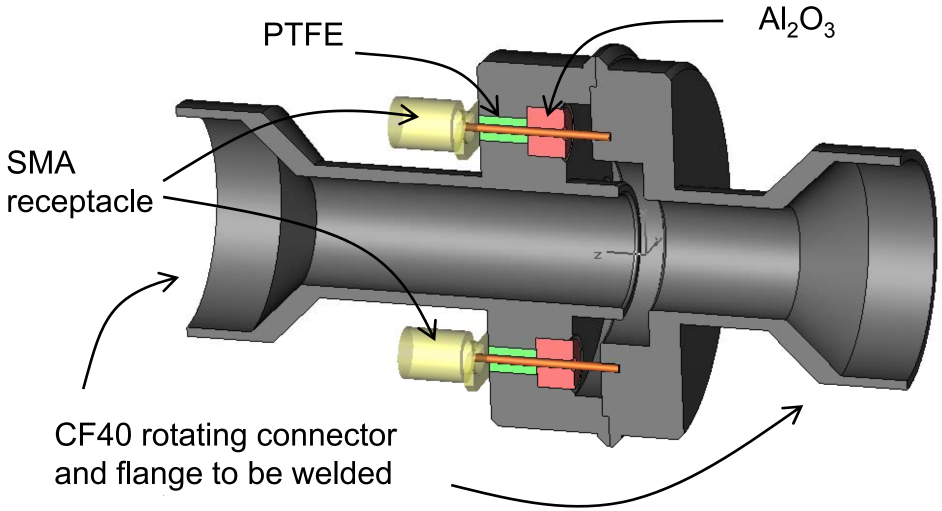
- **BPM developed for the CTF3 probe beam CALIFES**:

  - designed with a large frequency separation between monopole and dipole modes, as well as a low loop exposure to the electric fields

  - operated in single and multi-bunches modes

- 6 BPMs will be installed on the CTF3 probe beam





RF Characteristics

RF characteristics measured on the 6 BPMs in laboratory.

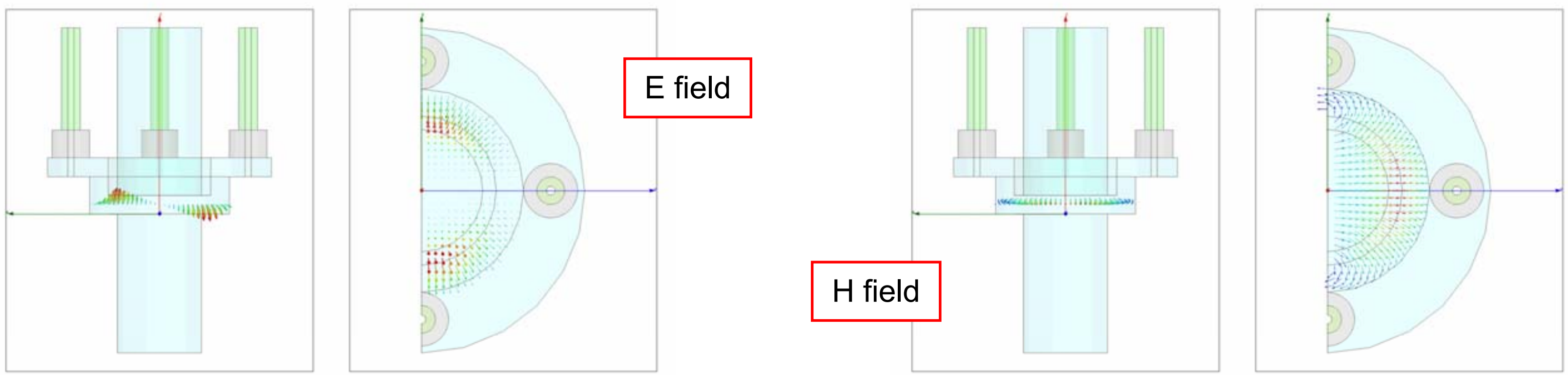
- **Standard deviation on the dipole frequency : ~ 12 MHz**
- **Monopole frequency ~ 3.99 GHz**

Eigen modes	F (GHz)	Q_l	R/Q_l (Ω)	R/Q_l (Ω)
	Measured in lab	Measured in lab	Offset 5 mm	Offset 10 mm
Monopole mode	3991	24	22.3	22.2
Dipole mode	5985	43	1.1	7

- With **Matlab and the HFSS calculator**, we computed **R/Q Ratio**.

R: the Shunt impedance and Q: the quality factor

$$\frac{R}{Q} = \frac{V^2}{2 * \pi * f * W} \qquad V = \left| \int E(z) * e^{jkz} dz \right| \quad \text{and} \quad k=w/c$$

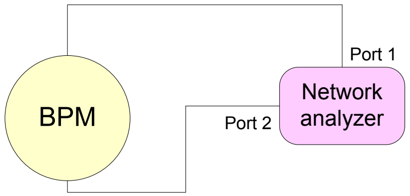


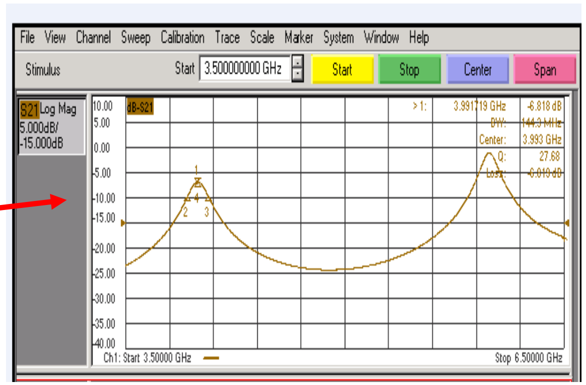
Cross Talk of the Cavity BPM

- **Due to tolerances in machining, welding and mounting, some small distortions of the cavity symmetry are generated**.

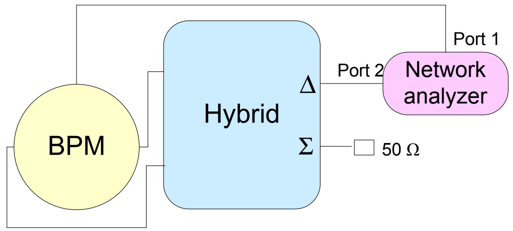
A beam displacement in the 'x' direction gives not only a reading in that direction but also a non zero reading in the orthogonal direction 'y'.

This **asymmetry** is called **cross talk**.



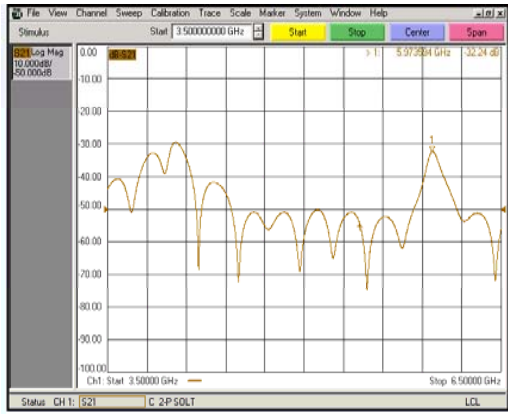


Monopole and dipole transmission measured by the network analyzer



Representation of the cross-talk measurement

Transmission of 2 antennas positioned at 90°



From those measurements, the **cross-talk isolation** value is estimated >30 dB.

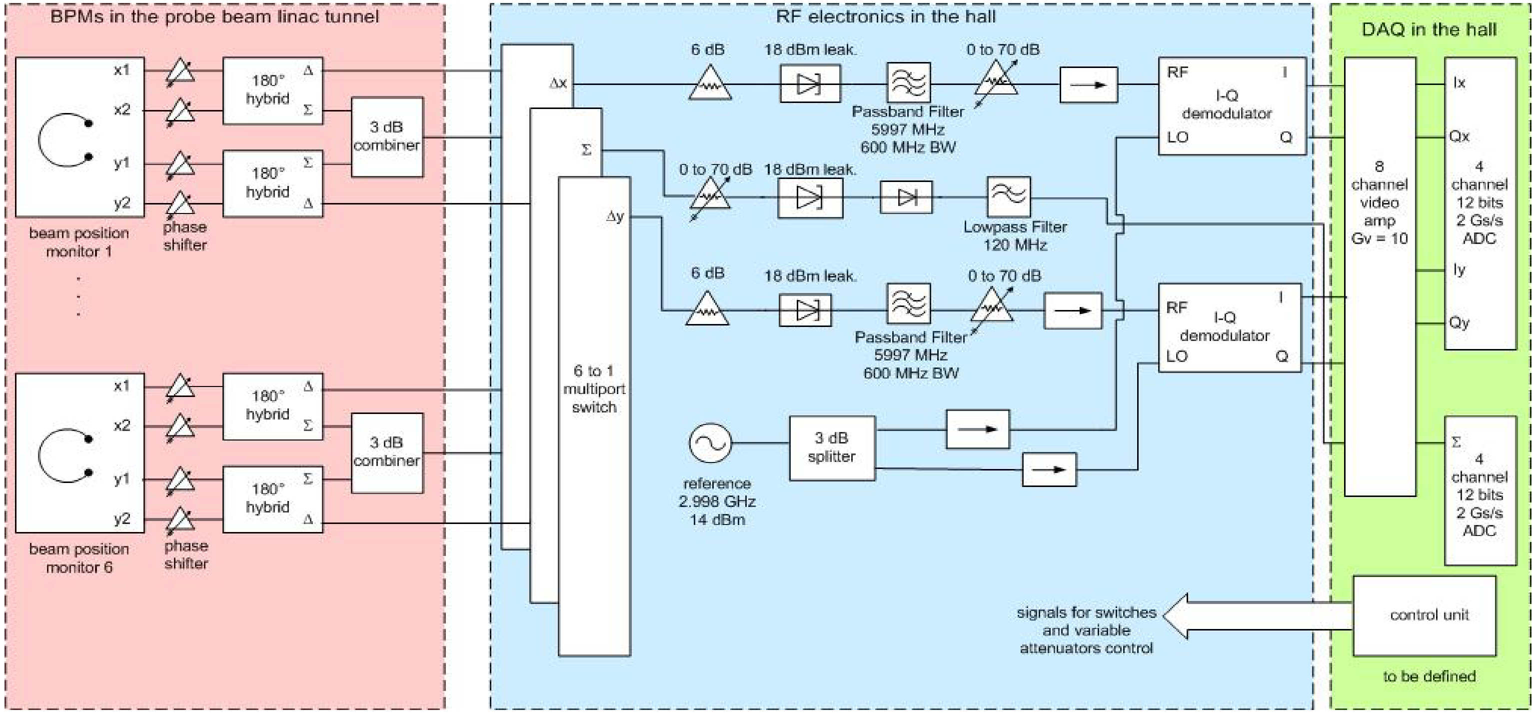
Signal Processing

➤ The rejection of the monopole mode, on the Δ channel, proceeds in **three steps** :

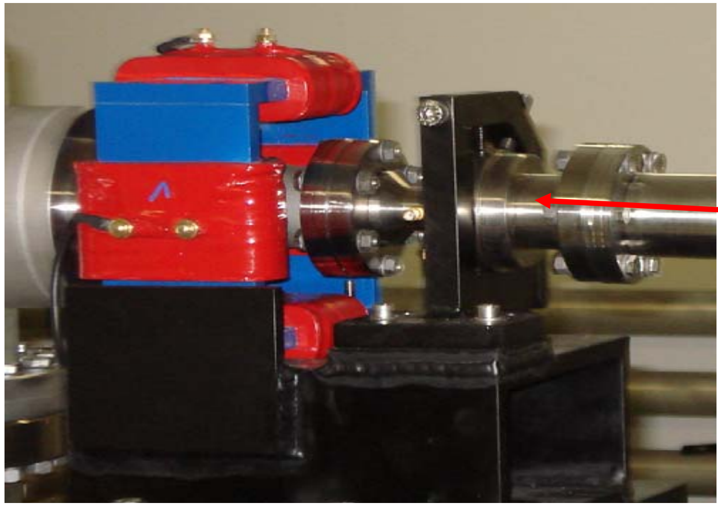
- a rejection based on a hybrid coupler having isolation higher than 18 dB in the range of 2 to 8 GHz.

- a frequency domain rejection with a band pass filter centered at the dipole mode frequency. Its bandwidth of 600 MHz also provides a noise reduction.

- a synchronous detection carried out with an I/Q demodulator.

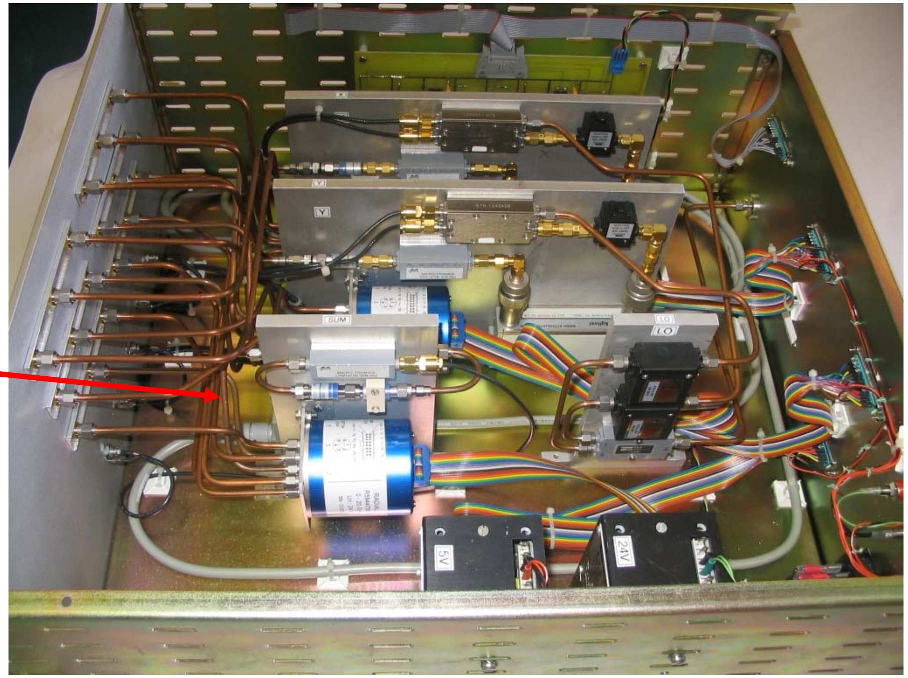


Re-entrant Cavity BPM CALIFES (3)



Re-entrant cavity BPM installed on the CTF3 probe beam

Signal processing electronics of the re-entrant BPM



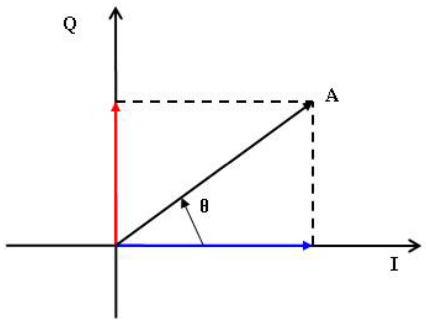
Waveform processing

- **As there is one electronics for 6 BPMs, a intermediate frequency is necessary**
- **Signals coming from 4 channels Ix, Iy, Qx, Qy with a frequency ~ 100 MHz**
- **Sampling** of signals with an Acqiris board.
- **Digital Down Conversion (DDC)**

- raw waveform multiplied by a local oscillator of the same frequency to yield a zero intermediate frequency

- Real and imaginary parts of each IF are then multiplied by a 60 coefficient, symmetric, finite impulse response (FIR), low pass filter with 40MHz 3dB bandwidth

- **Beam offset** is given by



$$A := \sqrt{I^2 + Q^2}$$

$$\cos(\theta) := \frac{I}{A} \qquad \sin(\theta) := \frac{Q}{A}$$

Mathcad Model

CALIFES
CTF3

➢ To assess the **system performance**, a model (cavity+signal processing) is elaborated with a **Mathcad code** based on **Fourier transforms**.

$$T_\Delta = \left|\left(\left(S_m - S_d\right)Hc.Hdiff1\right) + \left(\left(S_m + S_d\right)Hc.Hdiff2\right)\right|$$

Δx

Pick up Signal => $S_{pickup} = \sum S_i$

One resonant mode => RLC circuit (Si)

Model of hybrid coupler 180° based on S parameters

Cables transfer function with attenuation and dispersion = Hc

T_Δ

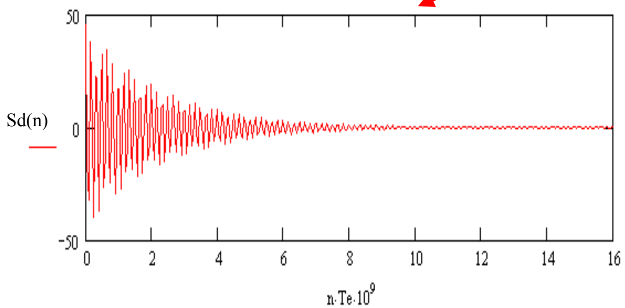
Transfer function 600 MHz band pass filter at 5.997 GHz defined by CAD Code

LO signal => $\sin((\omega_d) + \Phi)$

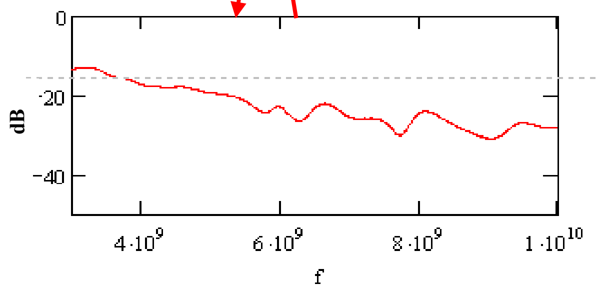
Transfer function 200 MHz low pass filter defined by CAD Code

Sampling at the peak for a significant beam offset

$V_\Delta(\Delta x)$

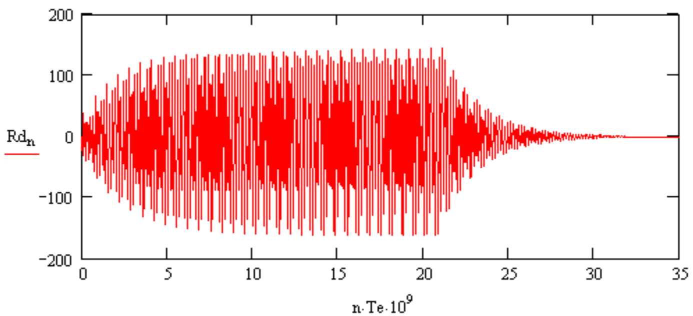


Dipole mode signal in single bunch mode

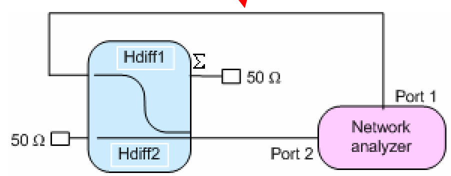


$$I_{hybrid} = 20 * \log\left(\left|Hdiff1 + Hdiff2\right|\right)$$

Isolation of the 180°hybrid



Dipole mode signal in 32 bunches mode



S parameters measurement of the hybrid 180°

Theoretical Noise

➢ **Noise** determined by the thermal noise and the noise from signal processing channel

Thermal noise : $P_{th} = k_b * T * BW$

kb = Boltzmann's constant (1.38*10-23J/K), BW (Hz) = bandwidth of the signal processing channel, and T (K) = room temperature.

Noise from the signal processing: $P_n = NF * G * P_{th}$.

NF= total noise figure of the signal processing channel, G = gain of the signal processing and Pth = thermal noise.

Total noise introduced into the system by the electronics can be evaluated by the noise figure in a cascaded system : $NF = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 * G_2} + \dots$

NF = total noise factor of the signal processing, Fi and Gi respectively the noise factor and the gain of component i.

dapnia cea saclay

Theoretical Resolution

• **Position resolution:** RMS value related to the minimum position difference that can be statistically resolved.

• **Signal given by the model** (cavity+signal processing) simulation with a gain adjusted to get an RF signal level around 0 dBm on the Δ channel with 5 mm beam offset.

System	Signal Δ with 5 mm beam offset	Noise
Single bunch	590 mV	0.5 mV
Multi-bunch	590 mV	0.5 mV

Resolution ~ 3.2 µm with a measurement dynamic range +/- 5 mm

Time Resolution

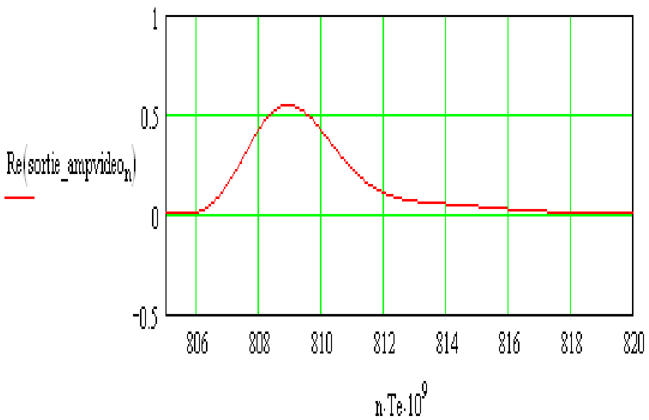
- **Damping time** is given by using the following formula

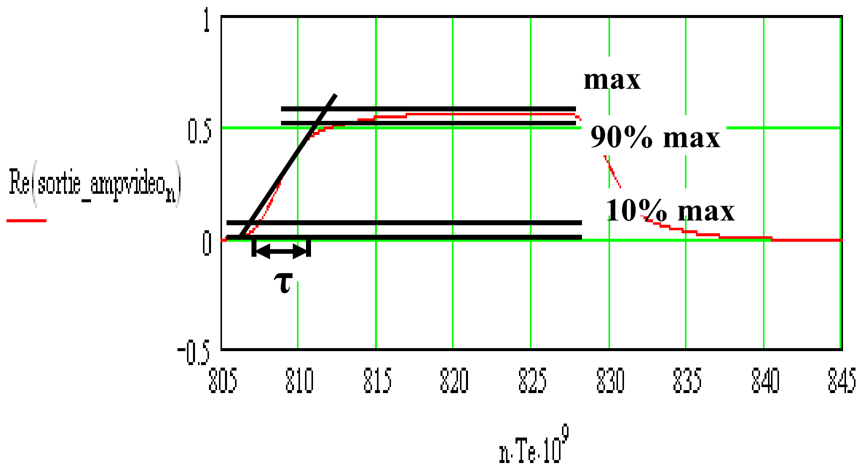
$$\tau = \frac{1}{\pi \cdot BW} \qquad BW = \frac{F_d}{Q_d}$$

Fd: dipole mode frequency
Q_ld: loaded quality factor for the dipole mode

Damping time of the cavity : 2.8 ns

- Rising time





Rising time: - single bunch mode ~ 2.8 ns
- multi bunches mode (32 bunches) ~ 4.5 ns

Conclusion

- Re-entrant cavity BPM features, designed for CALIFES:

  - Good resolution simulated
    (3.2 µm a dynamic range around +/- 5 mm)

  - Rising time single bunch mode = 2.8 ns
    multi bunches mode (32 bunches) = 4.426 ns

- Software / Algorithms still under development.

- First beam tests → June 2008

Acknowledgements

➢ Thanks to my colleagues from CERN and CEA who work on the CALIFES project:

Stéphane Deghaye
Wilfrid Farabolini
Francis Harrrault
Pierre-Alain Leroy
Fabienne Orsini
Lars Soby

Thank you for your attention