Stripline Beam Position Monitor Development for the CLIC Drive Beam

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BE-BI

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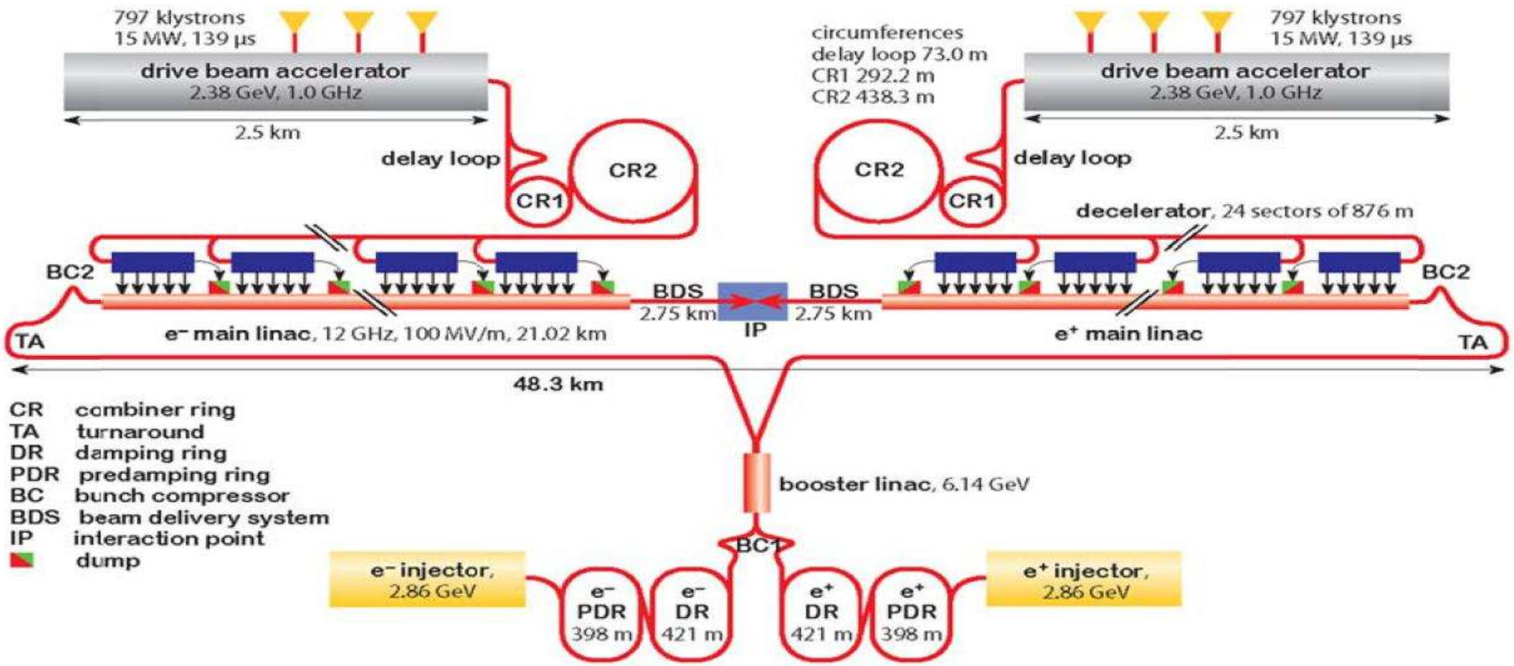
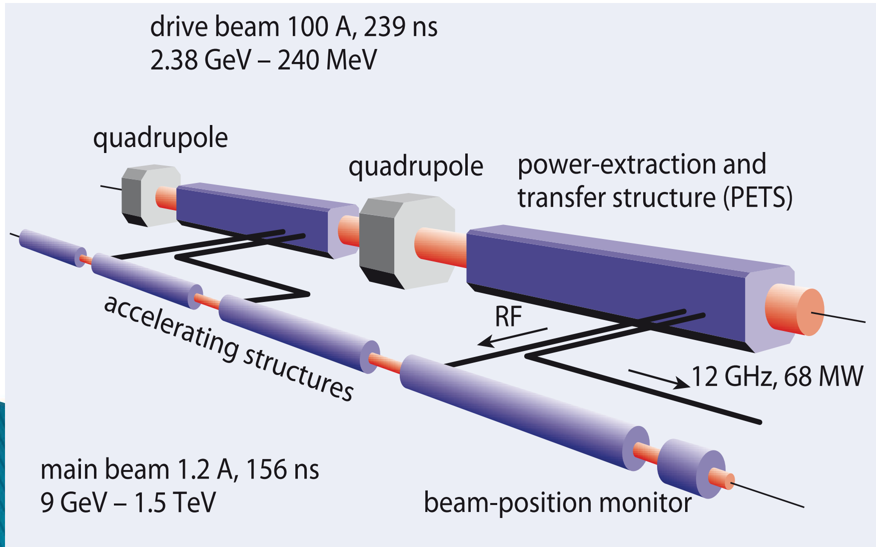
1- The CLIC Drive Beam





- CLIC: High energy e^-e^+ linear collider (3 TeV)
- Linacs: 100 MV/m gradient at room temperature.
- RF power for Main Beam acceleration obtained from high-current Drive Beam deceleration at the Power Extraction and Transfer Structures (PETS)

CLIC DB BPM Requirements

- Close proximity to PETS
  - 130 MW of RF power at 12 GHz propagating along the Drive Beam pipe (fc_{TE11} = 7.64 GHz).
  - Need to measure mW beam signals in proximity of MW RF pulses.
  - Suppression of 12 GHz PETS interference needed.

- Simple and economic design imposed by number of units and available installation space (<150 mm).

- Tight resolution and accuracy requirements.

BPM Requirements	
N° BPMs	41580
Beam current	100 A
Bunch frequency	12 GHz
Bunch length	10 ps
Train length	242 ns
Aperture	23 mm
Spatial resolution	2 µm
Time resolution	10 ns
Accuracy	20 µm

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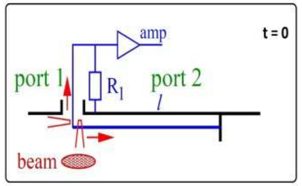
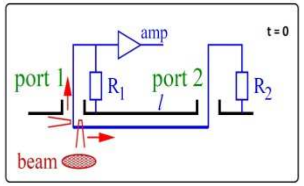
2 – Stripline BPM basics

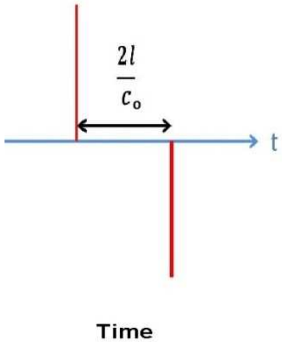
- 130 MW PETS RF interference at 12 GHz needs to be suppressed.
  - BPM technology with a suitable frequency response.

- Two possible versions of stripline BPM:
  - Compact: downstream short-circuited electrodes, simple, low cost.

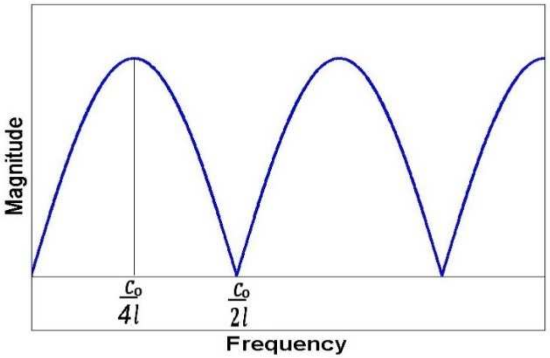


  - Terminated: 8-port, increased tunability, loop-through calibration possible.



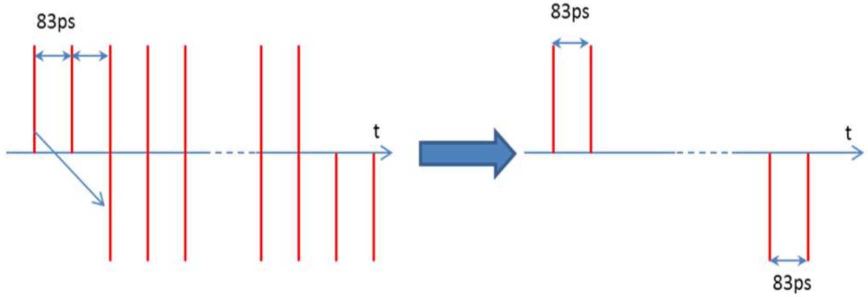


$$z(t)=\frac{Z_c}{2}\left[\delta(t)-\delta\left(t-\frac{2\ell_{\text{strip}}}{c_0}\right)\right]$$



$$Z(\omega)=j\,Z_c\,e^{-j\frac{\omega\ell_{\text{strip}}}{c_0}}\sin\left(\frac{\omega\ell_{\text{strip}}}{c_0}\right)$$

Z_c : beam to stripline coupling impedance



- If $\frac{2l}{c_0} = NT_{bunch}$ → Bunch cancellation

  (N^{th} notch tuned to f_{bunch})

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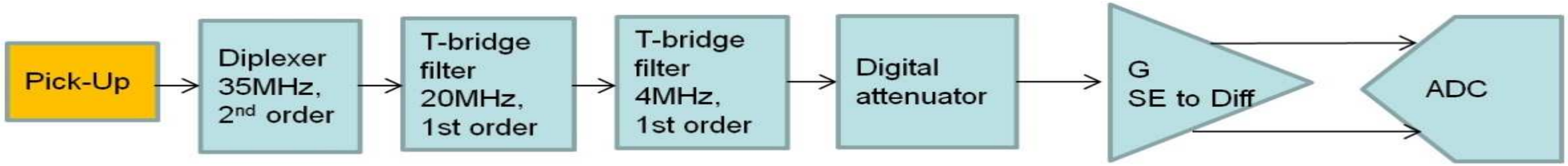
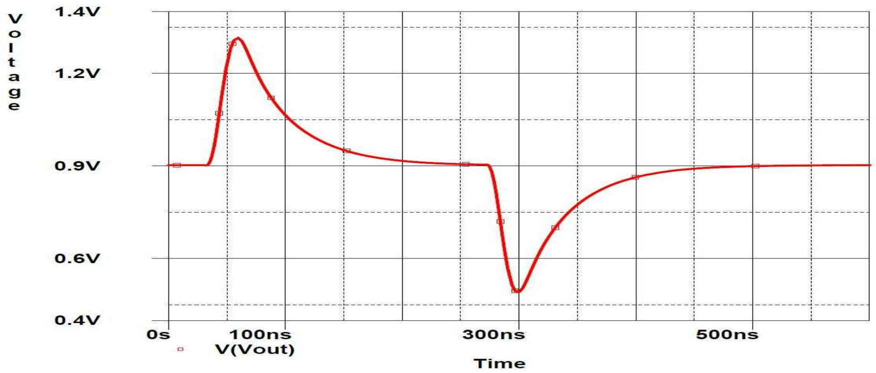
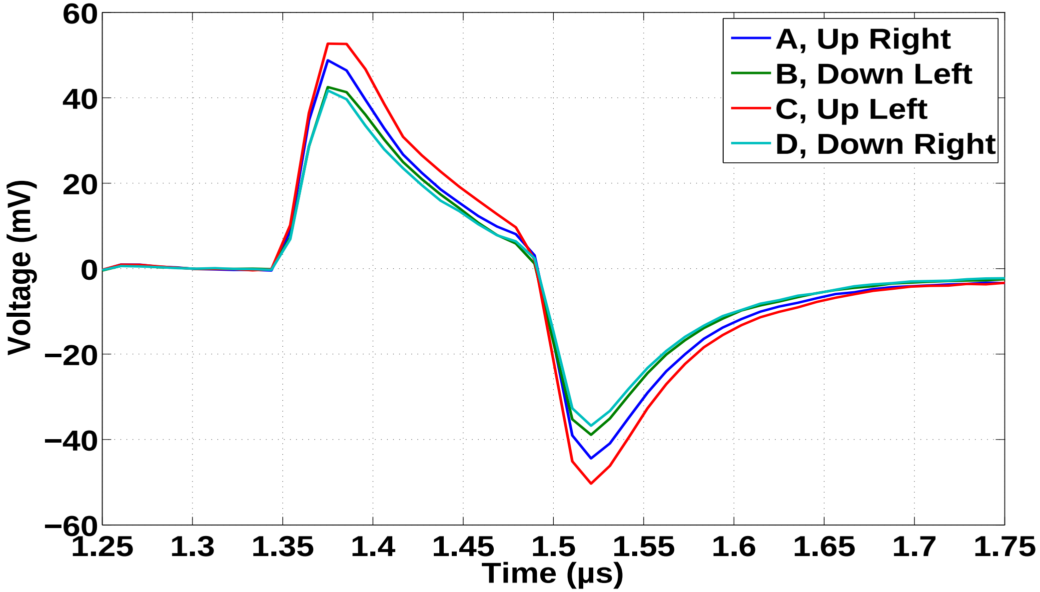
3 – Acquisition electronics



PSPICE Simulation



Measurement for centered beam



- Position estimates as $x = k\Delta/\Sigma$, being k the linear calibration coefficient and Δ the difference, Σ the sum of opposite electrode signals.
- <u>Analog signal shaping</u> required for correct acquisition of short and intense BPM electrode signals → Integration / Low-Pass (LP) filtering before ADC.

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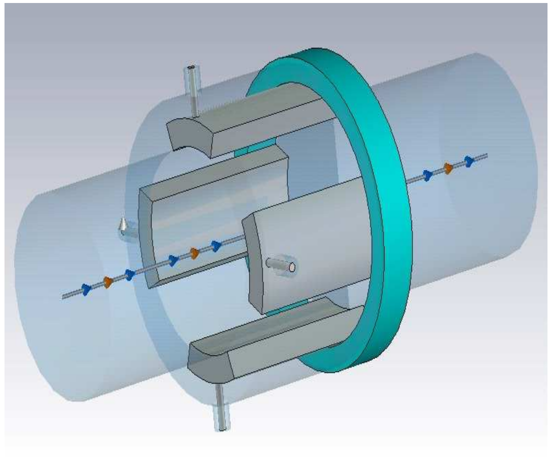
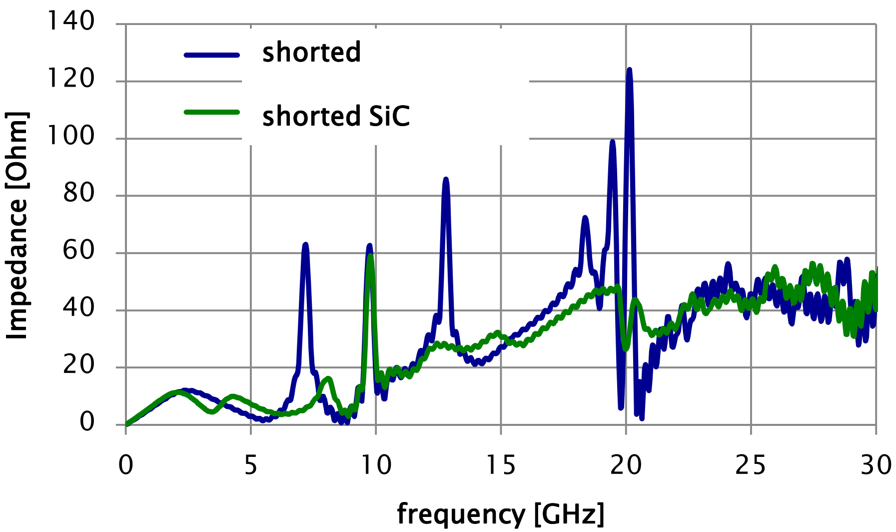
4 – Stripline BPM Compact Prototype

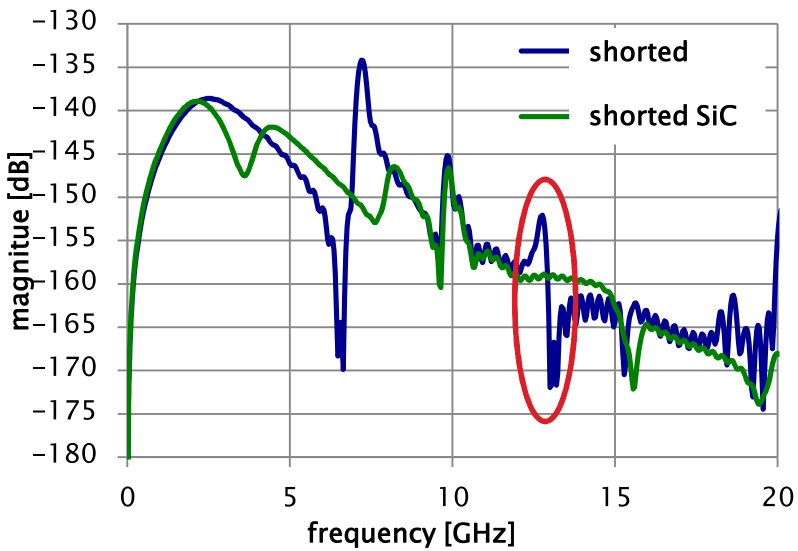


- Compact prototype (l=25 mm, tunes 2nd notch).
- SiC ring added to damp peak of longitudinal wake impedance at 12 GHz.
- Distorsion of the transfer function → No notch at 12 GHz!
- Geometrical issues (TM_{01})

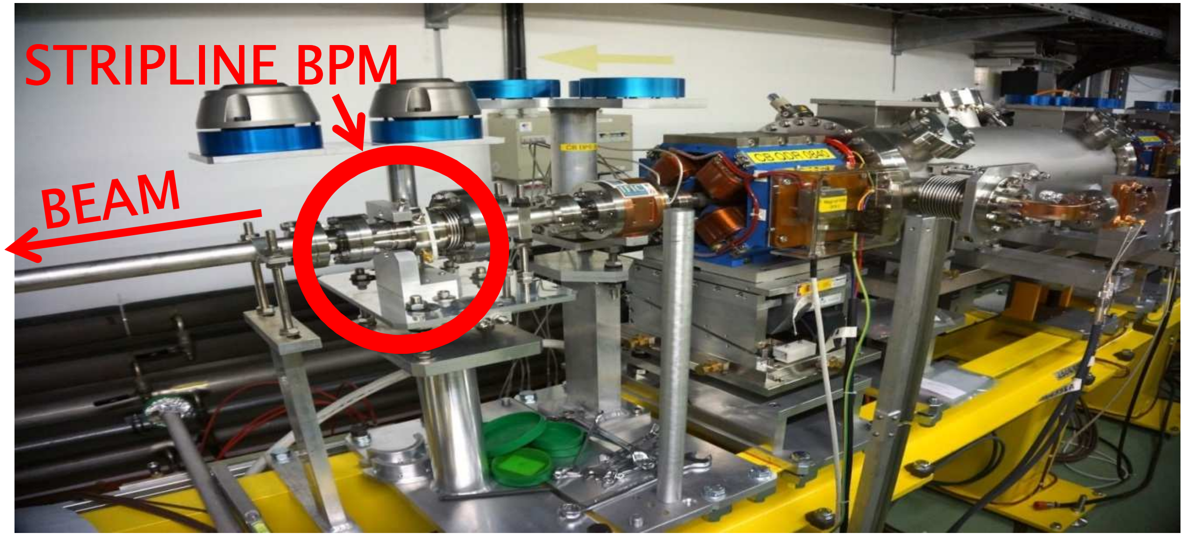
Longitudinal Wake Impedance

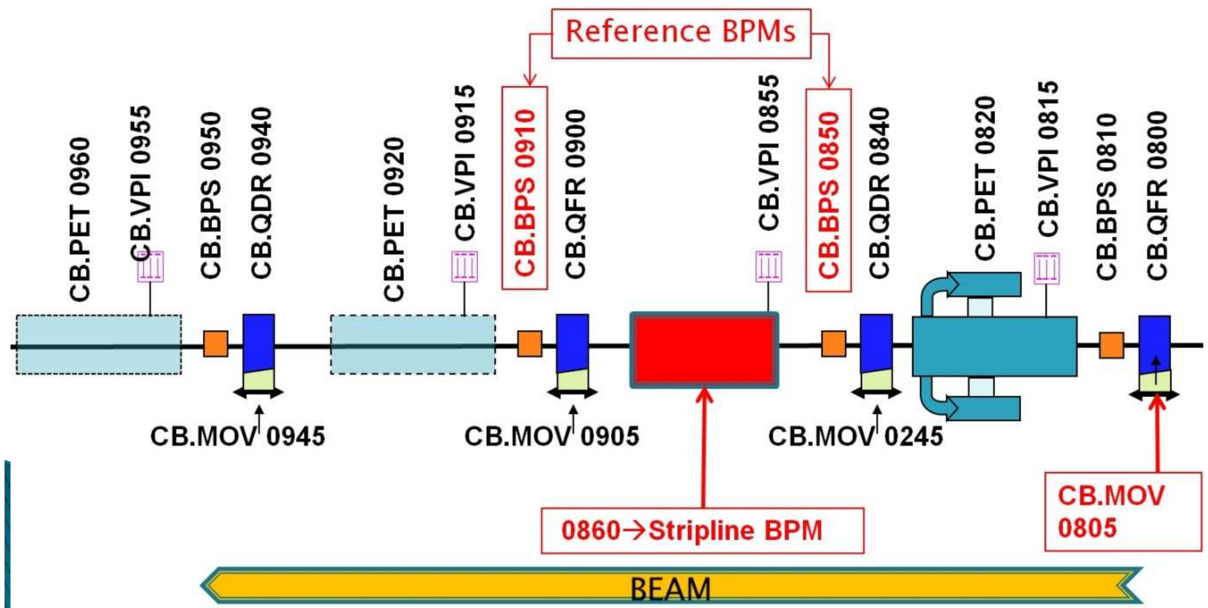


Transfer function



Beam Tests at CTF3



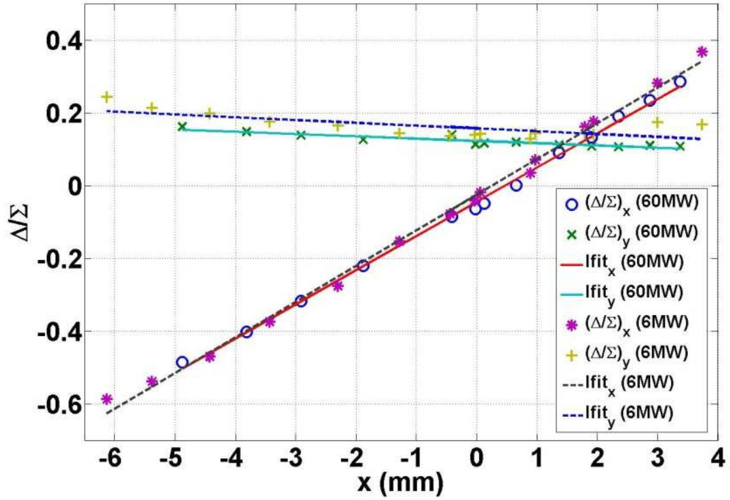


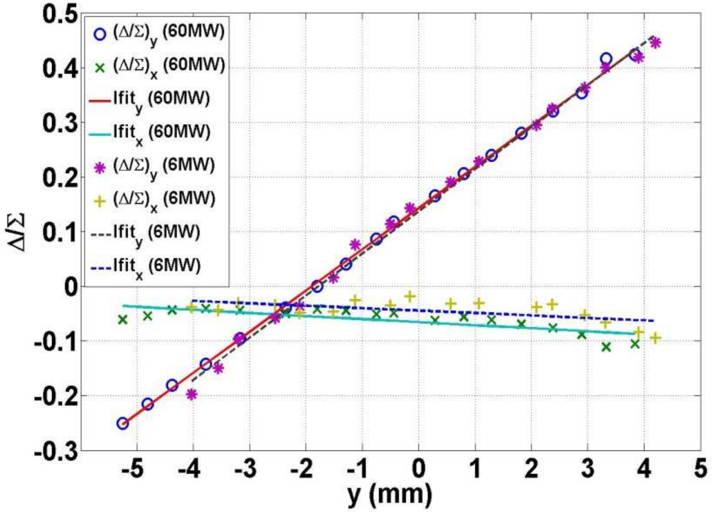
- TBL, pos. 0860
- Evaluate the influence of 12 GHz PETS interference (130 MW)
- Beam steered ±5 mm by moving QFR 0800.
- Reference BPMs: BPSs 0850 and 0910

Beam Tests at CTF3

- Two test scenarios: 6 MW and 60 MW PETS interference at 12 GHz

$x_{H,V} = (S_{H,V}^{-1})\Delta/\Sigma + EOS_{H,V}$		
Parameter	**6 MW PETS RF power (Beam current: 10 A)**	**60 MW PETS RF power (Beam current: 22 A)**
V sensitivity S_V (m^{-1})	72.4±1.8	75.3±0.6
H sensitivity S_H (m^{-1})	98.1±1.7	94.2±1.4
V offset EOS_V (mm)	-1.76±0.07	-1.91±0.02
H offset EOS_H (mm)	0.24±0.05	0.46±0.04
V RMS lin. error (μm)	250.42	92.73
H RMS lin. error (μm)	182.87	120.00





Beam Tests at CTF3

- Linearity/Sensitivity Test Results:
  - Reduced vertical sensitivity compared to simulated value (100 m^{-1}).
  - An offset (up to ~190 μm) appears for the plane not being swept. Further study is needed.

- Resolution Test :
  - RMS value of 85 consecutive shots (upper bound):
    - Stripline BPM: 9.5 μm (H) and 12.1 μm (V) (for 100 A)
    - BPS 0850: 14.1 μm (H) and 17.8 μm (V) (for 100 A)
    - BPS 0910: 16.1 μm (H) and 14.7 μm (V) (for 100 A)

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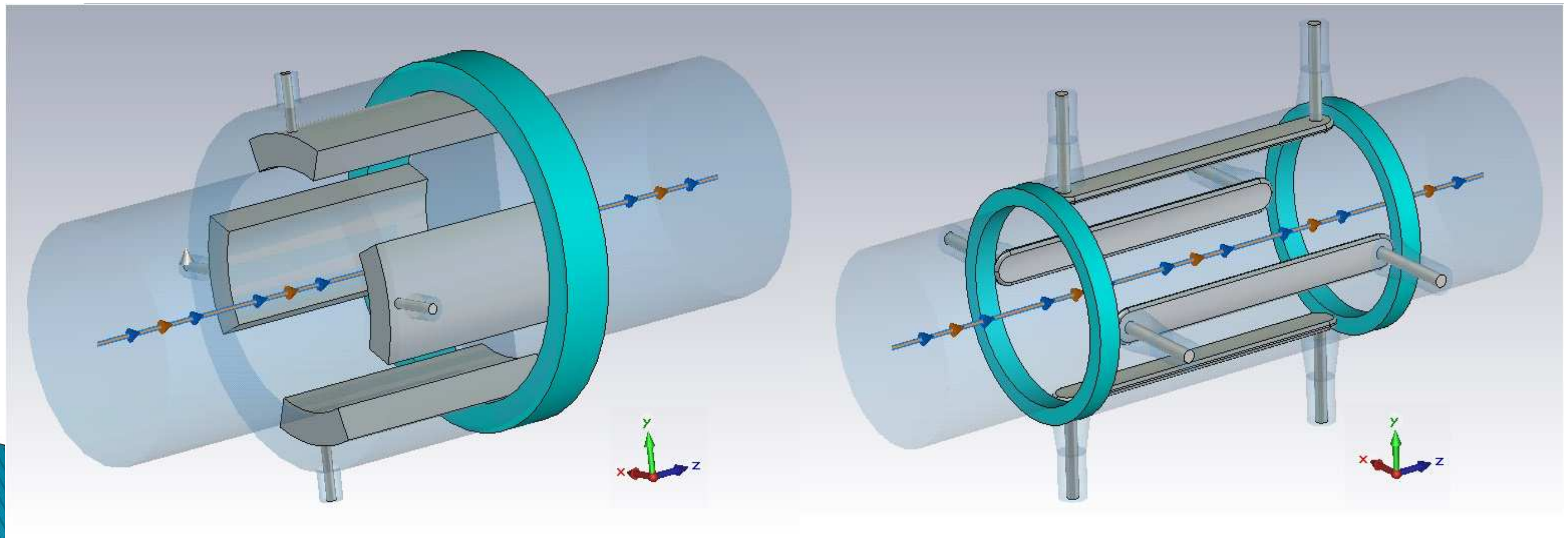
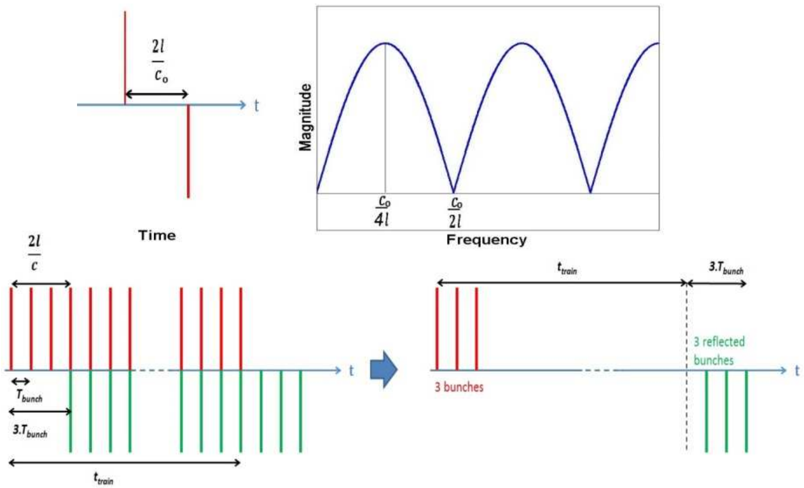
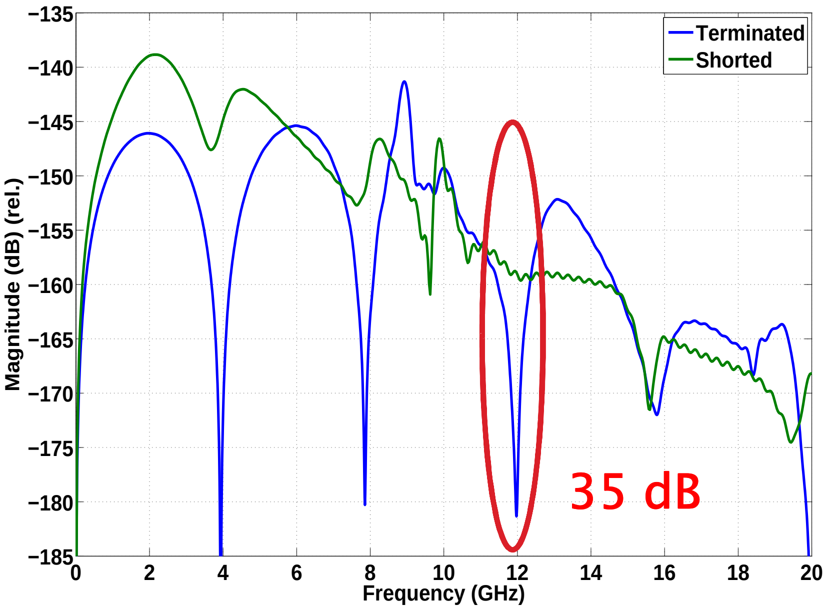
5- Stripline BPM terminated prototype

- First prototype provides insufficient suppression of the 12 GHz CLIC RF power signal.
- Longitudinal dimensions are very close to transverse ones (25 mm vs 23 mm) → non-ideal transfer response (non TEM fields).
- New design intends to tune the third notch of the frequency response to 12 GHz → electrode length l=37.5 mm.
- Option of a loop-thru calibration via the downstream ports.

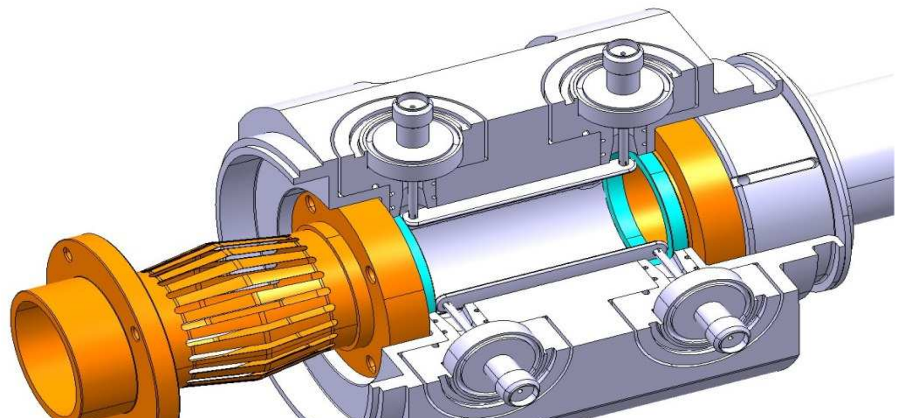


5- Stripline BPM terminated prototype



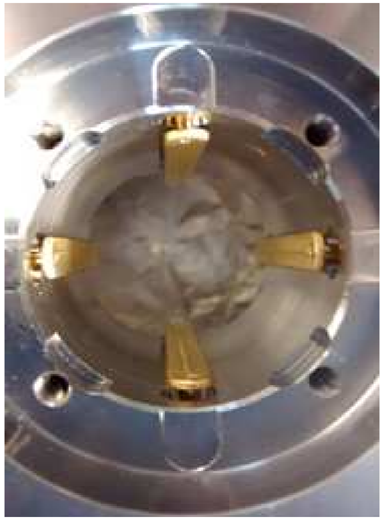


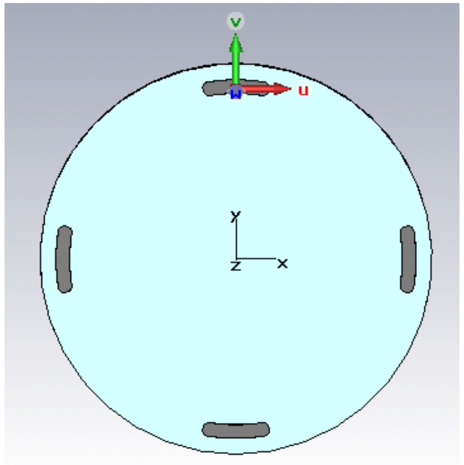
Parameter	Shorted BPM	Terminated BPM
Stripline length	25 mm	37.5 mm
Angular coverage	12.5% (45°)	5.55% (20°)
Electrode thickness	3.1 mm	1 mm
Outer radius	17 mm	13.54 mm
Ch. Impedance	37 Ω	50 Ω
Duct aperture	23 mm	23 mm
Resolution	2 µm	2 µm
Accuracy	20 µm	20 µm
Time Resolution	10 ns	10 ns

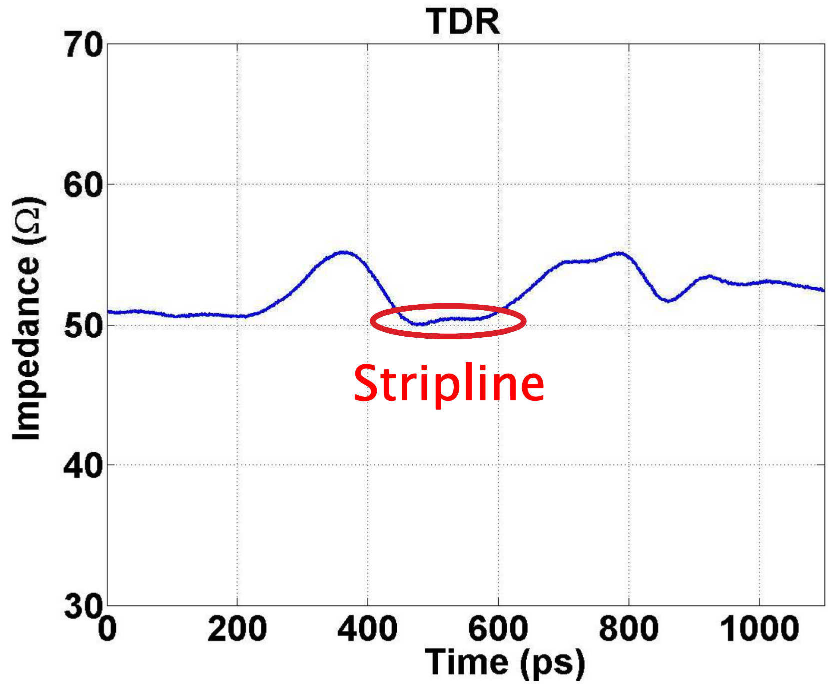


D. Gudkov BE-RF

5- Stripline BPM terminated prototype



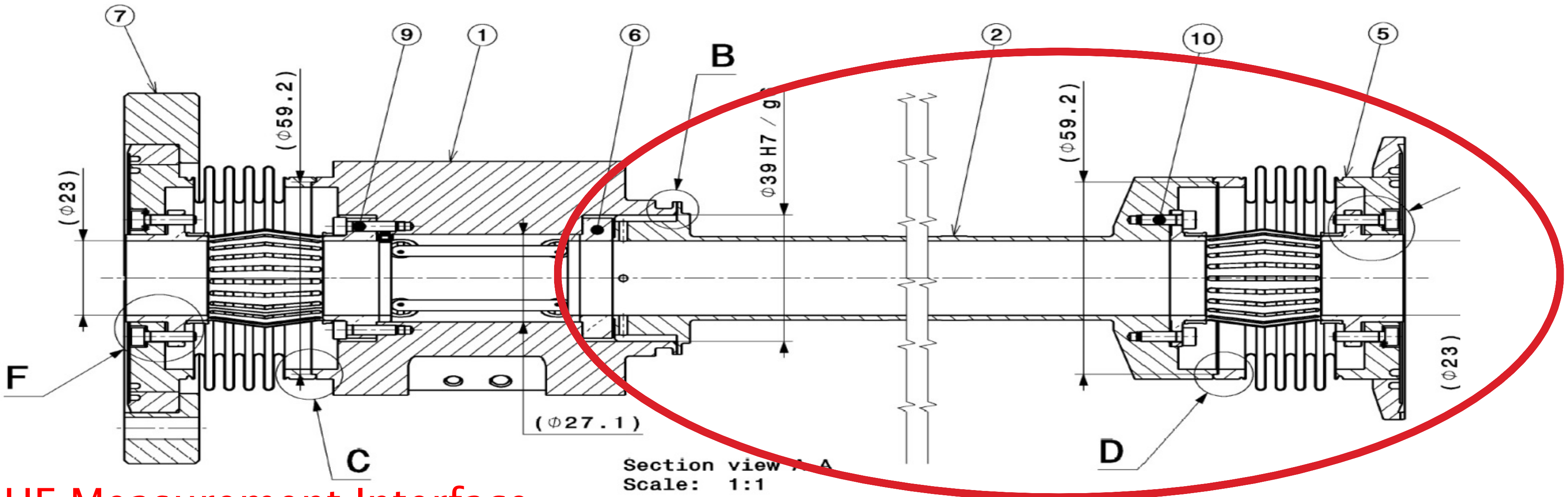




- Z_C extremely sensitive to electrode and feedthrough pin fabrication tolerances ($\Delta Z_C = \pm 3.5\ \Omega$ / 0.1 mm).

- Target range: $Z_C = 50 \pm 1\ \Omega$

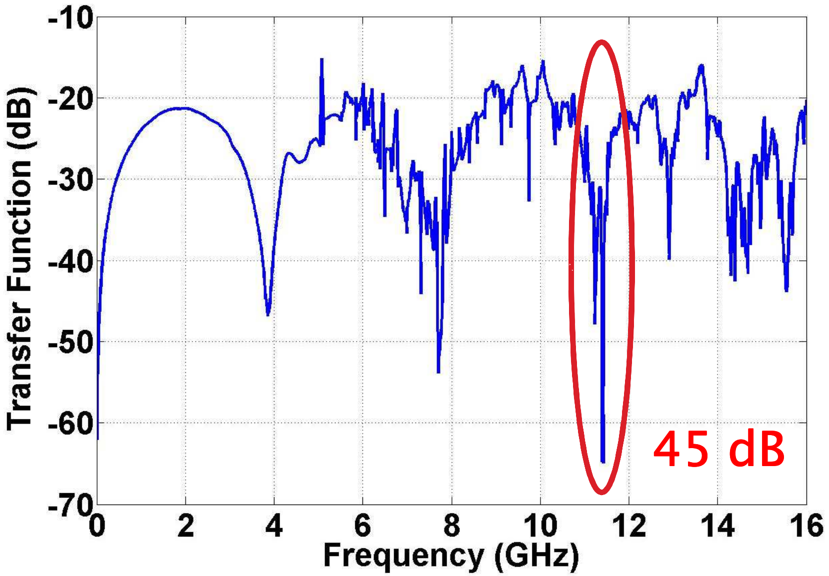
Transfer Function Measurement

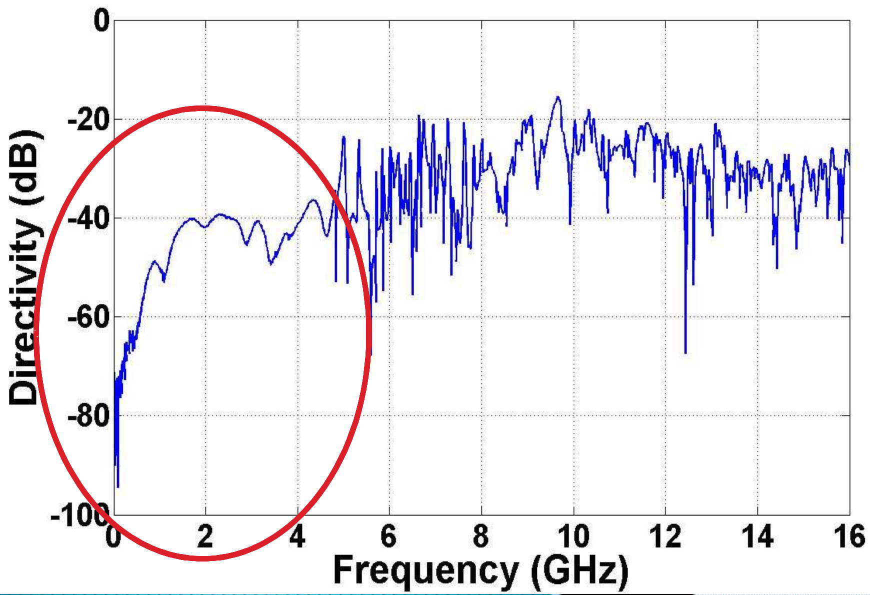


HF Measurement Interface

No Flange

Transfer Function Measurement





- 45 dB-deep 3rd notch, moves between 11.4-12 GHz → Non-ideal HF measurement flange.

- Directivity: ~40dB up to 4 GHz→ LHC (25-30 dB)

Contents

6- Conclusions and future work

- Compact prototype
  - Insufficient suppression of 12 GHz PETS interference.
  - Good linearity/sensitivity results with beam.

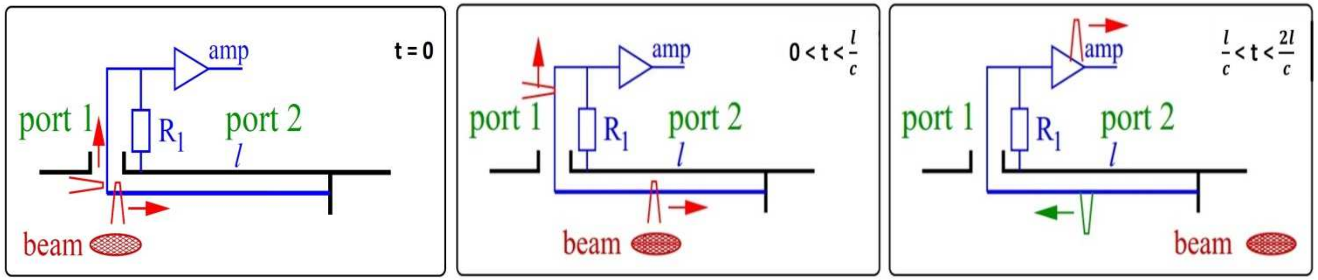
- Terminated prototype
  - Improved suppression of 12 GHz PETS interference.
  - Practical assembly aspects and cost to be optimized.

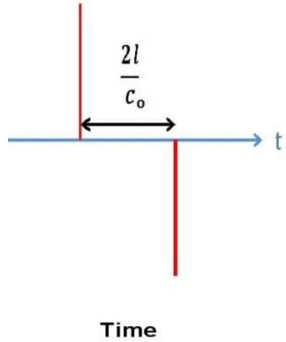
- Plans for 2014/2015
  - TF measurement with alternative methods (bead pull)
  - Beam test at CTF3 (CLIC Module) of terminated prototype (2 units)
  - Study of alternative technologies (button, IPU,…)

Thank you

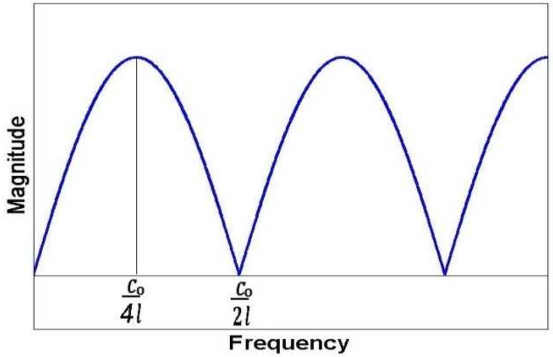
2 - Stripline BPM Basics

- Compact version (shorted electrodes)



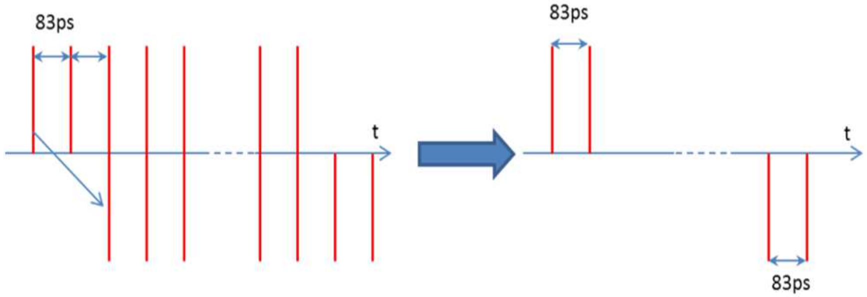


$$z(t) = \frac{Z_c}{2}\left[\delta(t) - \delta\left(t - \frac{2\ell_{\text{strip}}}{c_0}\right)\right]$$



$$Z(\omega) = j\,Z_c\,e^{-j\frac{\omega\ell_{\text{strip}}}{c_0}}\sin\left(\frac{\omega\ell_{\text{strip}}}{c_0}\right)$$

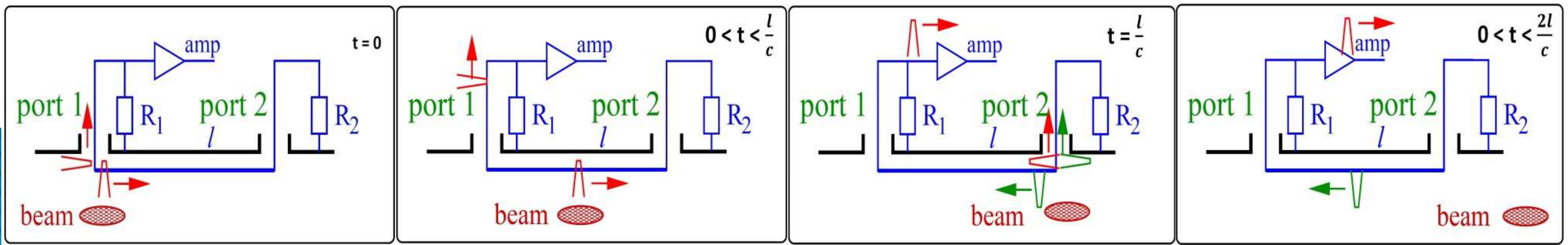
Z_c : beam to stripline coupling impedance



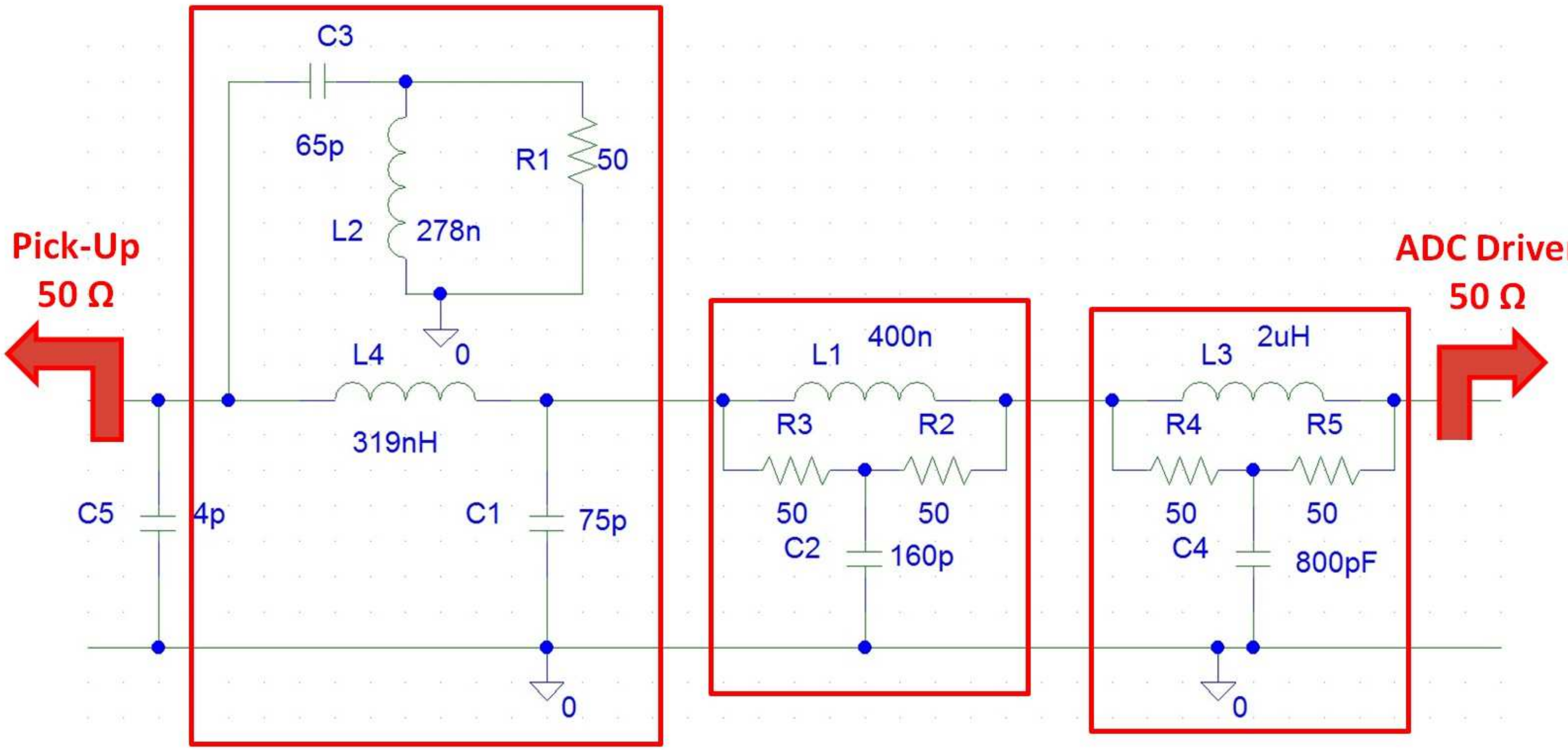
- If $\frac{2l}{c_0} = NT_{bunch}$ → Bunch cancellation

  (N^{th} notch tuned to f_{bunch})

- Terminated version (8 ports)



Passive filters for DB Stripline BPM

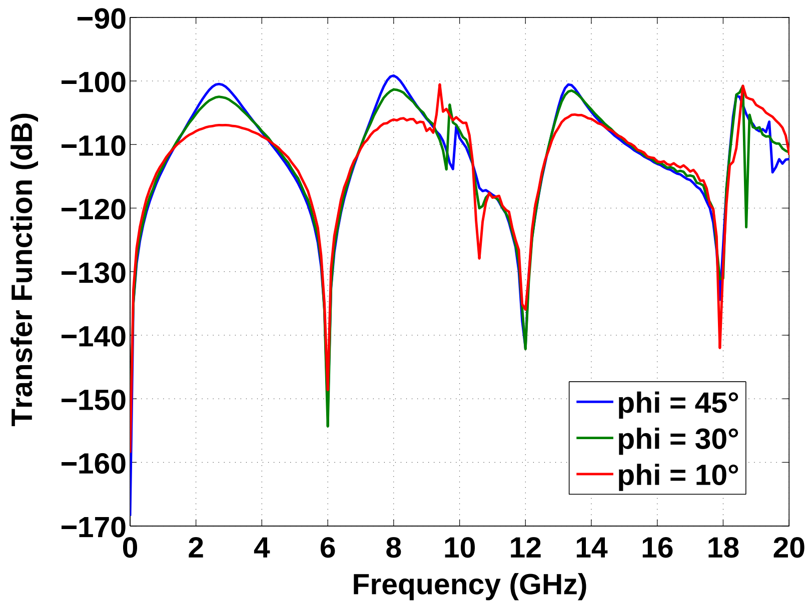


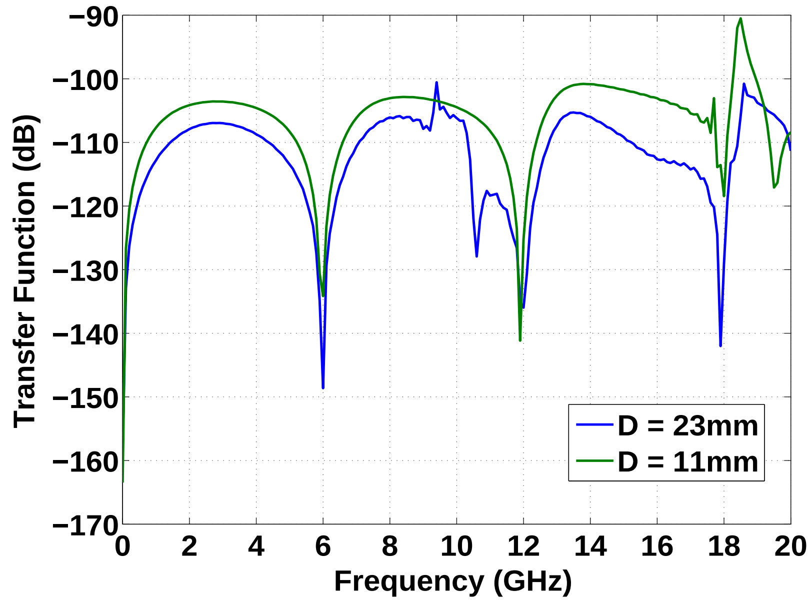
INPUT DIPLEXER 35 MHz
2nd order filter

BRIDGE-T 20 MHz
1st order filter

BRIDGE-T 4 MHz
1st order filter

Geometrical issues in compact prototype





- Lobe distortion grows with electrode width.
- TF sensitive to resonance at f_{TM_01}=9.99 GHz if aperture and electrode length become comparable.

Beam tests at CTF3