Topical Workshop on
Instabilities, Impedances and Collective Effects
TWIICE

Longitudinal Impedance characterisation of the CLIC-stripline in view of its test in the ALBA storage ring

CLIC-stripline = CLIC Damping Ring Extraction Kicker Prototype

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Introduction: ALBA Facility

- ✓ Synchrotron Light Source in Barcelona
- ✓ Up to 30 beamlines (7 on Day-1)
- ✓ Full energy Booster for Top-up injection
- ✓ 3 GeV Storage Ring, 268m circumference
- ✓ Emittance: 4.6nm*rad (4.3 design value)
- ✓ Maximum design current: 400mA

- ✓ SR Commissioning started 8 March 2011
- ✓ BeamLine Commissioning Autumn 2011

Motivation

ALBA joined the CLIC collaboration 2 years ago.

One of its contributions will be the test of the DR Extraction Kicker prototype in the ALBA ring

The design was made by Carolina Aguilar (her talk today)

my work is the evaluation of the heatload distribution for ALBA of a given design.

Heatload is an important issue of low emittance rings in particular the heatload distribution is crucial.

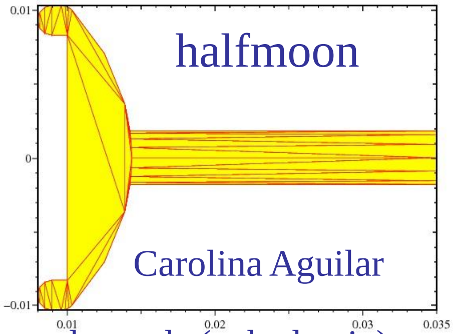
Pick-up like devices have a higher degree of difficulty due to external losses (Q-values necessary and Q_{ext} is not easy to compute).

But it is very interesting: The results of the CLIC-stripline are very clean and systematical. It is appropriate for a pedagogical study.

Outline:

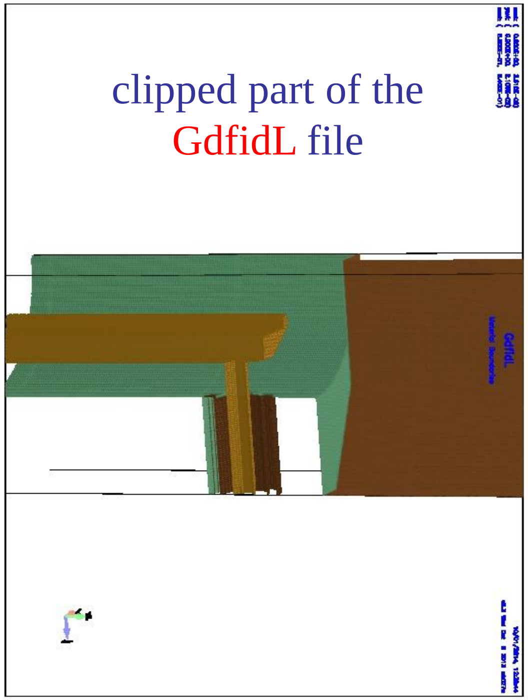
- Introduction
- Motivation
- the CLIC stripline geometry in the ALBA ring
- Stripline impedance: formula and GdfidL-computation
- Approach in frequency domain
- Heatload computation
- Heatload computation (How to get the Q-values)
- Output signals
- Estimation of Q_{ext} and power distribution (incoherent)
- Discussion of the possible coherent power
- Transverse impedance
- Conclusions and Acknowledgements

Building the geometry of the CLIC-stripline



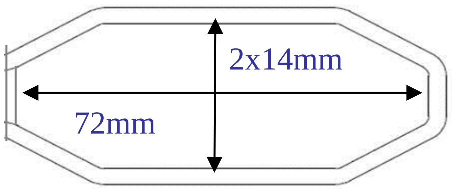
electrode (naked strip)
STL-file from CST

put the electrode in a round pipe
flanged to the ALBA pipe

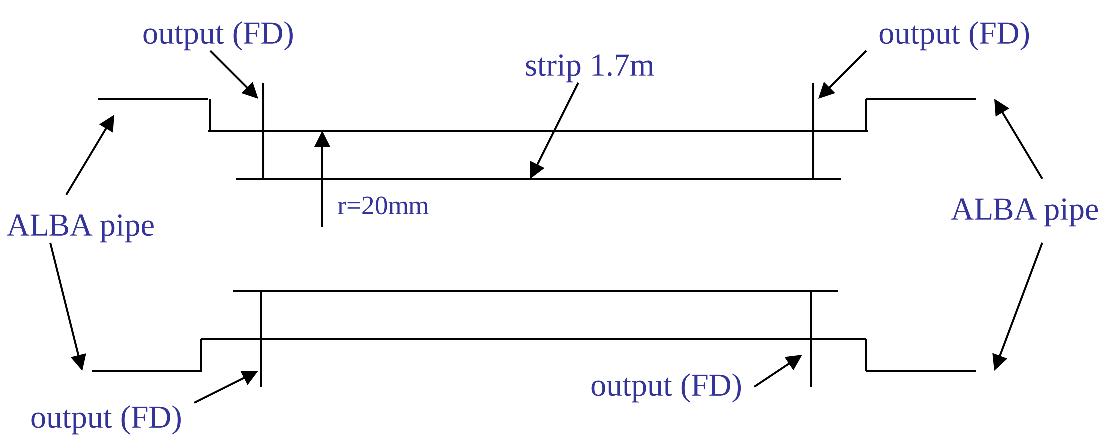


Make the feedthroughs long enough that they touch the border of the computational volume

ALBA beam pipe



top view of the CLIC stripline

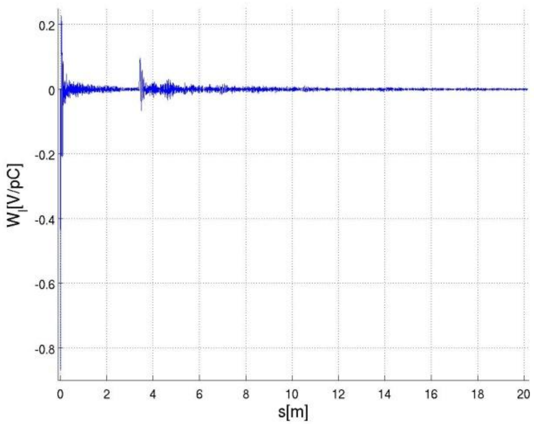


It is a horizontal stripline

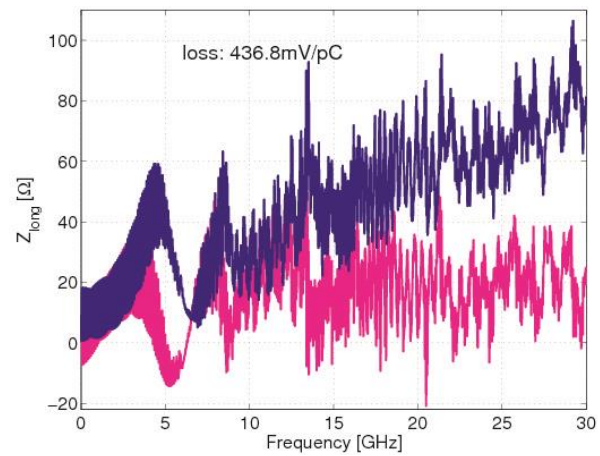
Coupling impedance of a stripline

$$Z_{\|}(k) = Z_L\, g^2[\sin(kL) + i\sin(kL)\cos(kL)] \quad with \quad k = \omega / c$$ (R.E.Shafer, IEEE TNS ‘85)

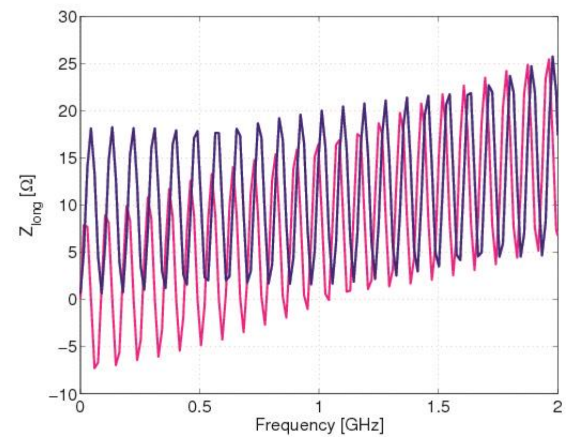
For L=1.7m one gets: f_1=44MHz, f_2=132MHz … many modes < cut-off(5.9GHz)



wake potential (20m) with GdfidL



Beam coupling impedance
κ_l is rather large(f<30GHz)
P_{loss}=35W@0.2A



agreement is very good

In case of a round beam pipe of 10mm the cut-off is at 11.5GHz, κ_l=0.83V/pC, P_{loss}= 66.4W

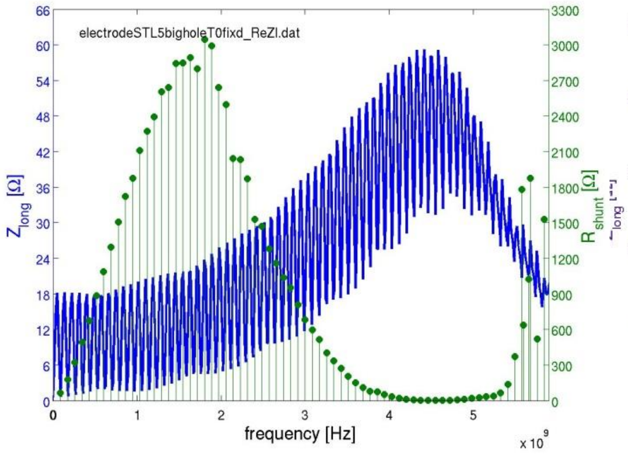
Wake potential does not provide us with information on the power dissipation distribution

Approach in frequency domain

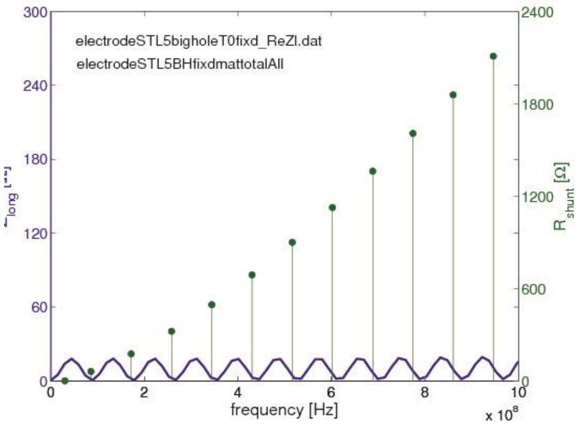
Pro: All the tools introduced for the treatment of modes (e.g. in a cavity) can be used.

Contra: in eigen-mode computations the open ports are closed (or simply don't exist).

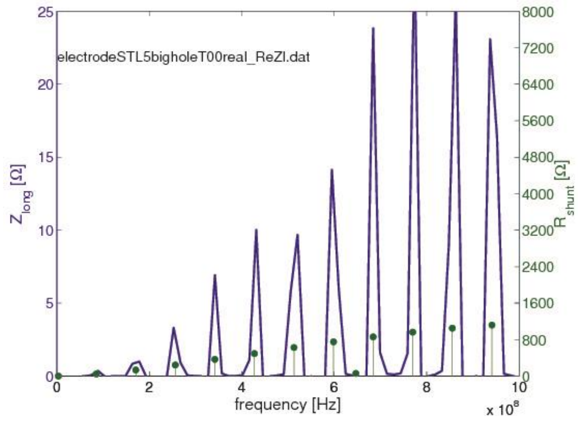
The stripline impedance formula (precedent page) already includes the open output ports.



global view



wake with open closed ports



wake with closed ports

$\kappa_{||}$(T-domain)=249mV/pC against $\kappa_{||}$(F-domain)=252mV/pC (f<5.9GHz) good agreement

Now we will assume each eigen-mode as a resonator with $R_{s,}$ (R/Q) and Q although their computation is very time-consuming.

Alternative: GdfidL with absorbing boundary conditions, but the identification of modes gets lost.

Heat load distribution computation

For the power repartition the quality factors of the different parts of the device are needed

n: number of mode

$$\frac{1}{Q_L^n} = \left(\frac{1}{Q_{strip}^n} + \frac{1}{Q_{Tank}^n} + \frac{1}{Q_{feed}^n} + \frac{1}{Q_{pipe}^n} \right) + \frac{1}{Q_{pipe\_rad}^n} + \frac{1}{Q_{ext}^n}$$

Once the Q's known, the modal and partial loss factors can be computed:

$$\kappa_{partial} = \sum_{f_n < 5.9GHz} \frac{\omega_n}{2} \exp\left(-(\omega_n \sigma_\tau)^2\right) \left(\frac{R}{Q}\right)_n \frac{Q_{Loaded\_n}}{Q_{partial\_n}}$$

sum over all modes n < cut-off

$$\kappa_{tot} = \sum_{partial} \kappa_{partial} = \kappa_{strip} + \kappa_{Tank} + \kappa_{feed} + \kappa_{pipe} + \kappa_{pipe\_rad} + \kappa_{ext}$$

2 large sums (Σmodes a. Σpartial) : manage all the data in a Excel sheet

$$P_n = N \kappa_n I_b^2 T_0$$

N: # bunches, I_b bunch current, T_0 revolution time

Heat load distribution computation (how to get the Q-values)

The geometry is segmented in parts (tank, strip, feed-through, pipe) of different material. The quality factor of a particular material segment is determined by switching on its resistivity whereas the other material segments are kept as PEC.

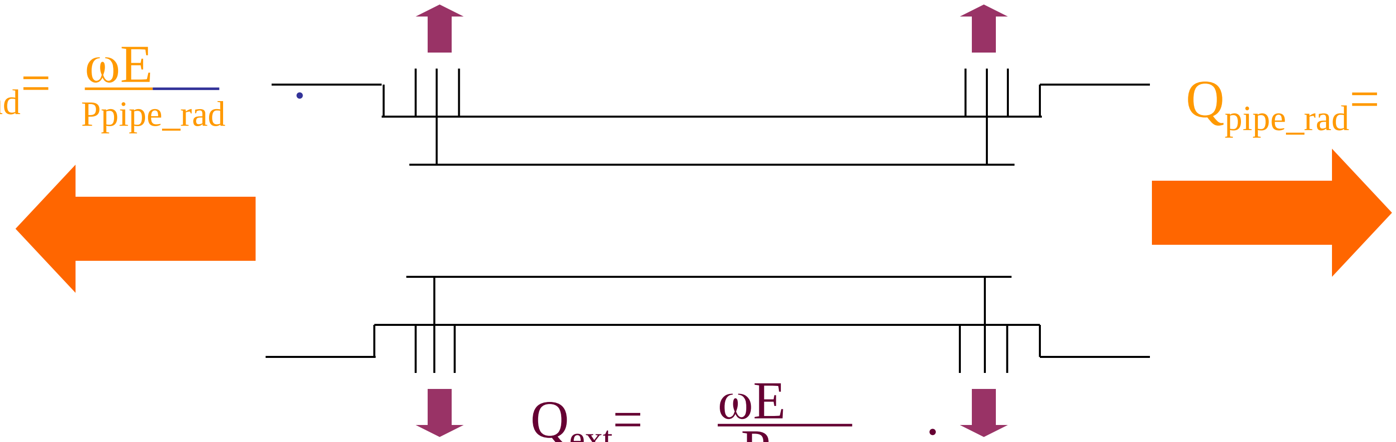
This is carried out for all material segments and for all modes.
Loss factors are computed for each mode and each segment.

$$\Big\} \rightarrow Q_{strip} \quad Q_{Tank} \quad Q_{feed} \quad Q_{pipe}$$

Determination of Q_{ext} based on exponential decay of the mode energy: $E = E_0 \exp(-\frac{\omega_n t}{Q^n_{ext}})$

For each mode the power flowing through the feedthroughs is observed. The average power is normalized on the product of angular frequency and energy residing in the strip-line in order to get $1/Q_{ext}$. This method is not very precise though.

$$Q_{pipe\_rad} = \frac{\omega E}{Ppipe\_rad}.$$



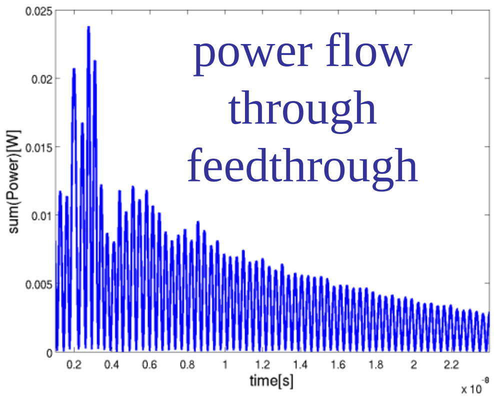
$$Q_{pipe\_rad} = \frac{\omega E}{Ppipe\_rad}.$$

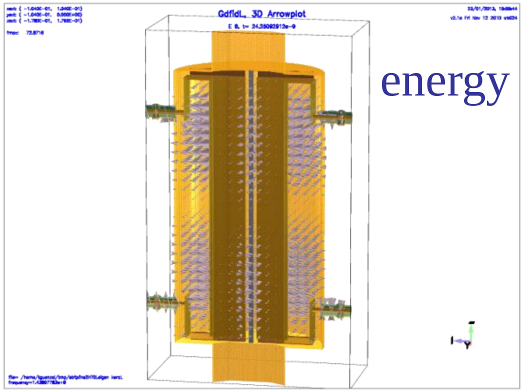
$$Q_{ext} = \frac{\omega E}{P_{feed}}.$$

Example:

mode in hor. stripline

f=1.439GHz





Q_L=140

But in both cases it is actually not like this.

1. Pipe radiation (Qpipe_rad) :

Noise for modes of low-frequency, but increases significantly for modes close to cut-off.

power flow via feed-throughs not considered here
all metallic parts considered out of Aluminium

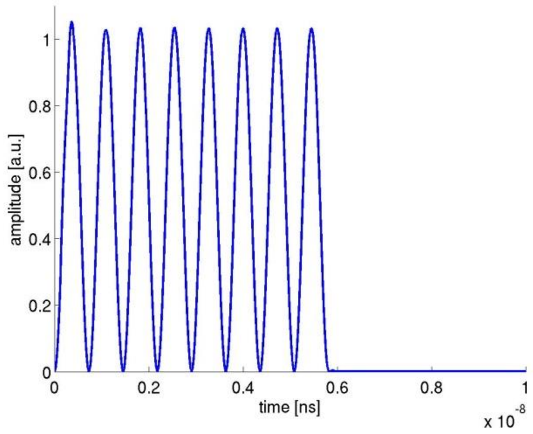
loss factor (<5.9GHz)	total	external	tank	strip	feedthrough	exit pipes	exit radiation
$\kappa_{\|\|}$[mV/pC](0<f<5.9GHz)	252.2	0	42.9	77.0	4.5	0.39	127.6
$\kappa_{\|\|}$[mV/pC](f<3GHz)	136.3	0	35.2	63.0	3.0	0.004	35.3
$\kappa_{\|\|}$[mV/pC](3<f<5.9GHz)	115.9	0	7.7	14.0	1.5	0.39	92.4

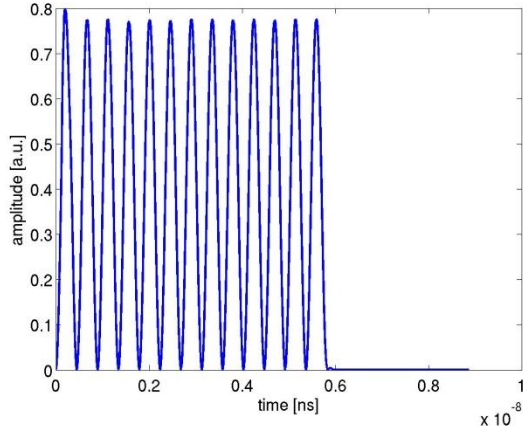
bunch length 5mm

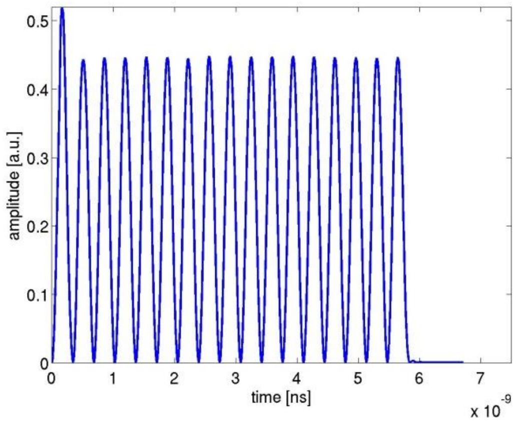
Modes just below the cut-off are not trapped anymore, they make up largest part of power loss.

Output signals of the stripline(as pick-up)

the power flow does not decay exponentially for the CLIC-stripline







All have the same length

Their frequency corresponds to the frequency of the excited mode

Almost the total energy leaves the stripline within less than t_D:=5.9ns = (L=1.7m)/c

This is much faster than any other dissipation process

It also shows the good quality of the stripline: There are no reflections at all.

For the ALBA kicker: There are apparently reflections visible in the power flow and the Z_{long}-spectrum is more irregular.

Estimation of Q_{ext}

The decay is not exponential, a decay time will attributed to it though

the reduction factor of the signal strength after t_D=5.9ns is roughly $10^{-2.5}$

$$\frac{E}{E_0} = 10^{-2.5} = \exp\left(-\frac{\omega_n t_D}{Q^n_{ext}}\right) \qquad Q^n_{ext} = \frac{5.9\,\omega_{res}[GHz]}{2.5\ln(10)}$$

P<5.9GHz(cut-off)	total	external	tank	strip	feedthrough	exit pipes	exit radiation
$\kappa_{\|\|}$[mV/pC]	252	244	0.4	0.8	0.1	~0	6.8
P_{loss} @0.4A [W]	80.6	78.1	0,13	0,26	0,03	~0	2,2
P_{loss} @10x32(0.2A)[	28.2	27.3	0,04	0,09	0,01	~0	0,8

Conclusion: In a good working stripline all excited power is only little dissipated but leaves the stripline through the feed-throughs

ALBA

Assumption of coherent superposition of wakes along the bunch train

Homogeneous filling: $P_{loss} = \sum \mathrm{Re}(Z(p\omega_0)) \, |\tilde{I}(p\omega_0)|^2$

$$\kappa_l \rightarrow \kappa_l \cdot \frac{D}{D^2 \sin^2\left(\pi \frac{f_r}{f_{RF}}\right) + 1}$$

with

$$D = Q_L \frac{2 f_{RF}}{\pi f_r}$$

assuming D≥M=448

Consequence: The κ_L of a resonance (almost) coinciding with a harmonic of f_{RF} is enhanced by D

$$\kappa_l \rightarrow \kappa_l \cdot D$$

resonance like a narrow-band resonator

On the contrary the κ_L of a resonance at $f_r \approx f_{RF}/2$ is suppressed by 1/D (assuming D ≥ M=448)

$$\kappa_l \rightarrow \kappa_l \cdot \frac{1}{D}$$

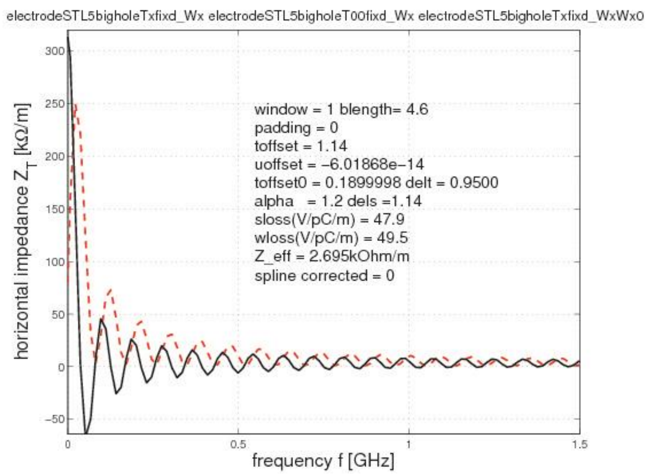
resonance like a narrow-band resonator

If the low external Q_{ext} is taken into account, D~2
coherent power loss does not need to be considered.

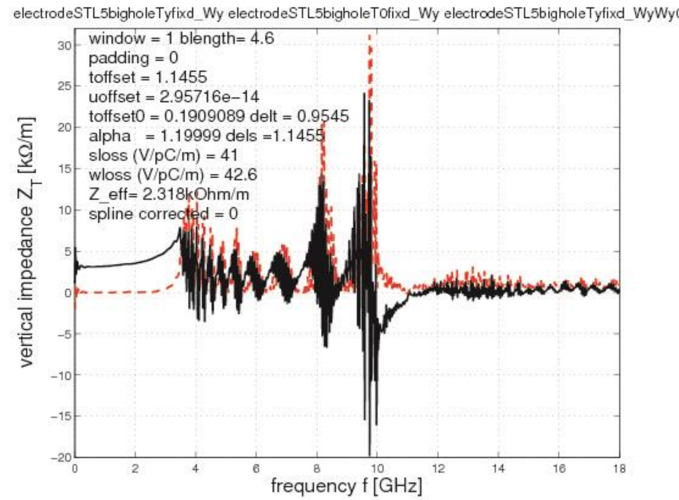
ALBA

Transverse impedance

Horizontal impedance



Vertical impedance



kickfactors @200mA	x'/x [µrad/m]	total [V/(pCm)]	total [V/(pCm)]	K_{quad} [V/(pCm)]	K_{dip} [V/pCm]
H	28.0	74.4	75.6	26.1	49.5
V	6.4	17.2	16.9	-25,70	42.6

The kicks are hardly measurable.

The stripline contributes
1.4% to the β-weighted geometrical V-budget and
3.2% to the β-weighted geometrical H-budget of ALBA

Conclusions

- Less than 1W stays in the CLIC stripline in 400mA beam operation since the excited modes can escape easily through feed throughs.
- No risk of coherent power loss.
- In terms of heat load the design of the CLIC stripline is perfect.
- Kicks generated by the transverse impedance are very small.
- A taper to the ALBA vacuum pipe is not necessary.
- The calculation of the external load mode by mode allowed us to study the output signals and to understand the low Q_{ext}.
  Using GdfidL with absorbing boundary conditions we wouldn't have seen that.

It is worth while to do these studies: the learn effect is rather high and the results are far from being self-evident.

Acknowledgements

Carolina Aguilar for providing me the details of the DR CLIC stripline

M.Dehler and G.Rehm for useful hints and discussions I learnt a lot from.

W.Bruns, the developper of GdfidL, who helped me a lot in understanding the output signals of the stripline.