LEIR extraction kickers impedance studies

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30-11-2020

Introduction

- Fast instabilities were observed in 2018 before RF capture.
- Harmful during LHC run -> lengthened the ion beam setup time!

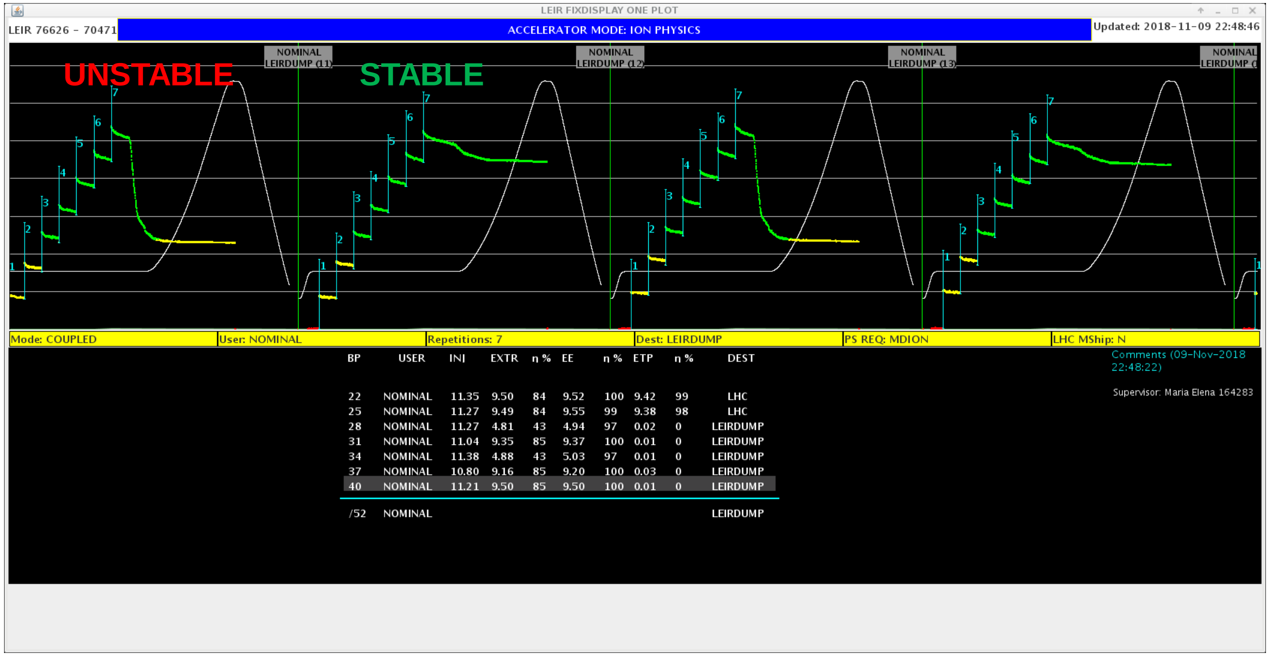
Complete list of known occurrences:

09/11/2018: elogbook link

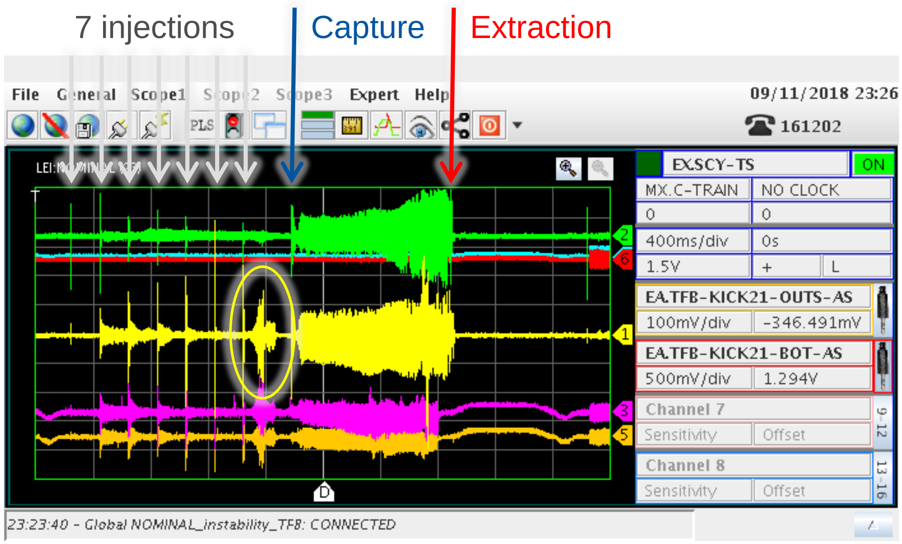
07/08/2018: elogbook link

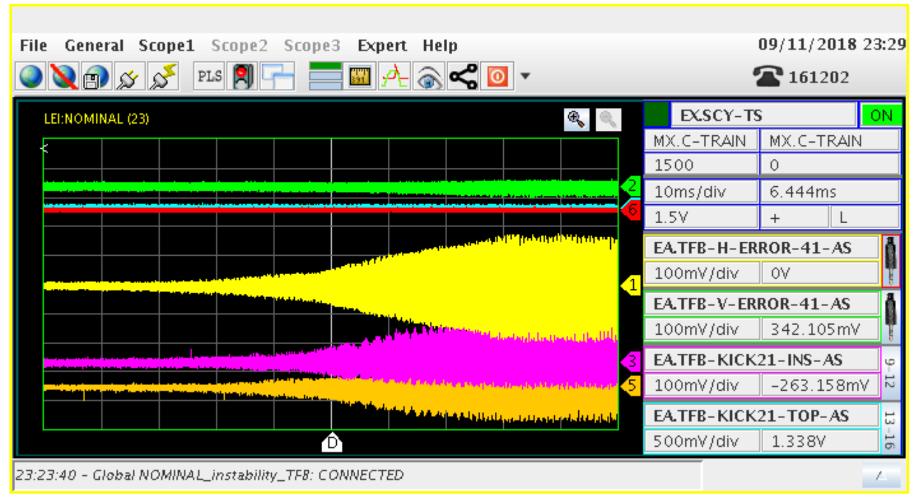
13/11/2018: elogbook link

15/11/2018: elogbook link



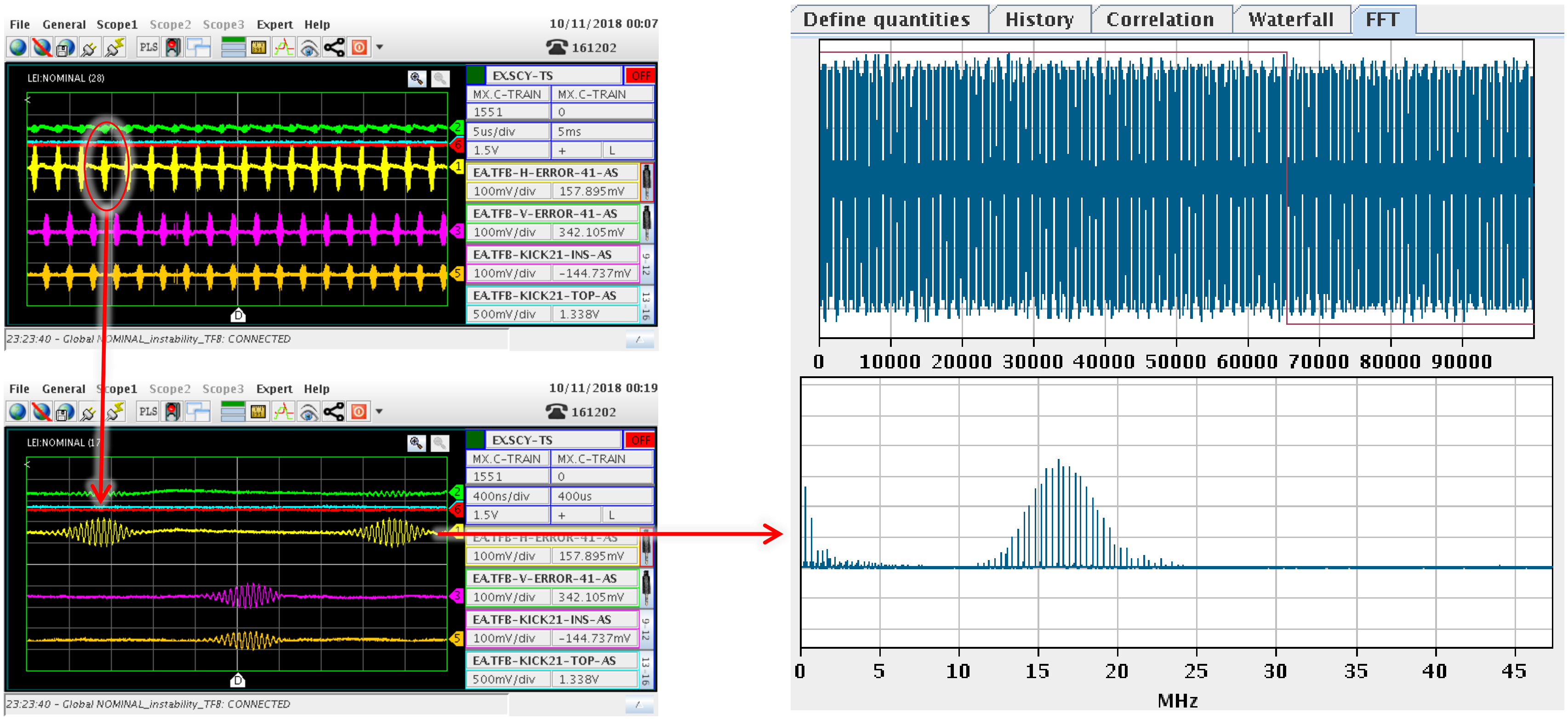
Coherent motion





- Beam looks horizontally unstable.
- Doubles amplitude in ~$20\ ms \rightarrow \tau = \frac{20}{\ln 2} \simeq\ 28\ ms$ [~ 10k turns]
- Damper was in operation

Frequency content



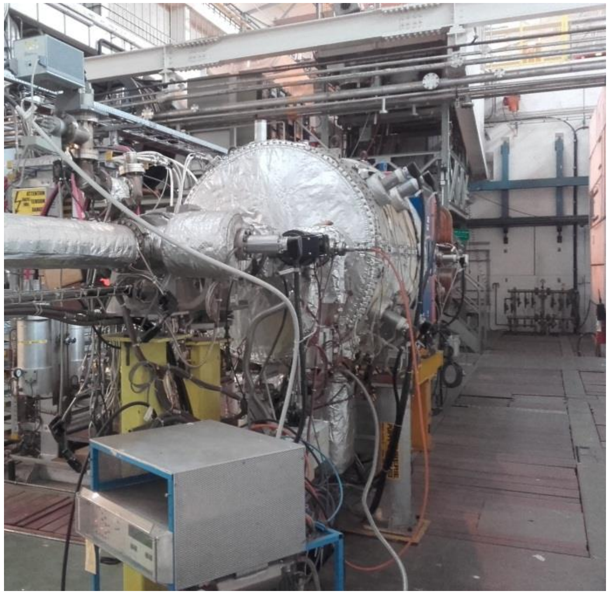
- Large amplitude from 10 to 20 MHz
- HOM: $f_r \sim 17$ MHz, $Q \sim 3-4$
- Not very reproducible, frequency seen to jitter

Seek for a source…

- Given the plane of instability, relatively low HOM frequency and low Q factor, we started to investigate the LEIR extraction kickers.

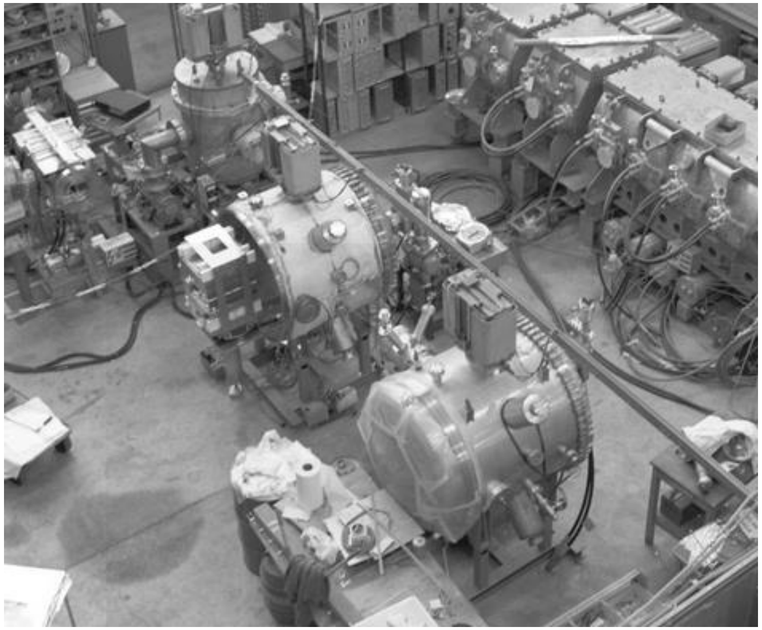
ER.KFH31

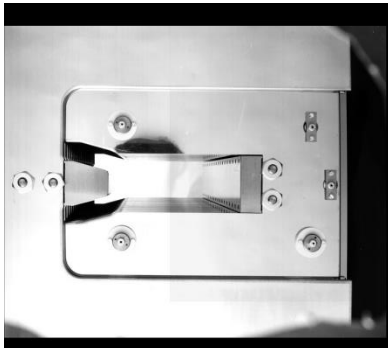
ER.KFH32-34

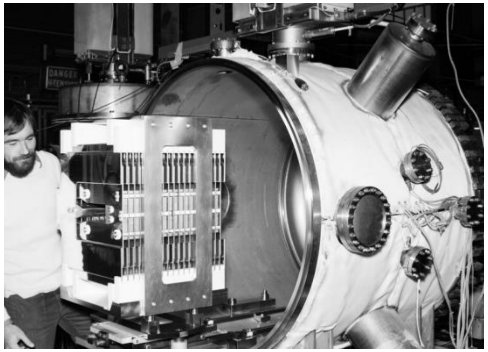


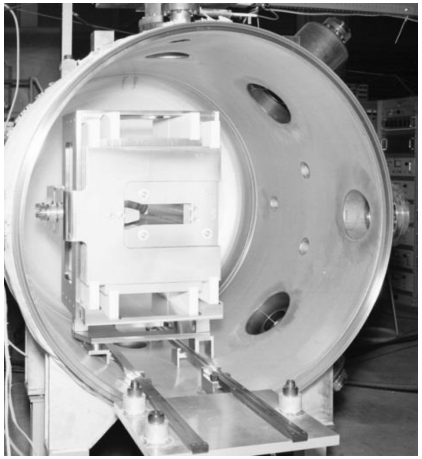
ER.KFH31 and ER.KFH32-34 are used in LEIR to extract the beam.
No CAD models available.

Pictures KFH3234 (LEAR 1981)





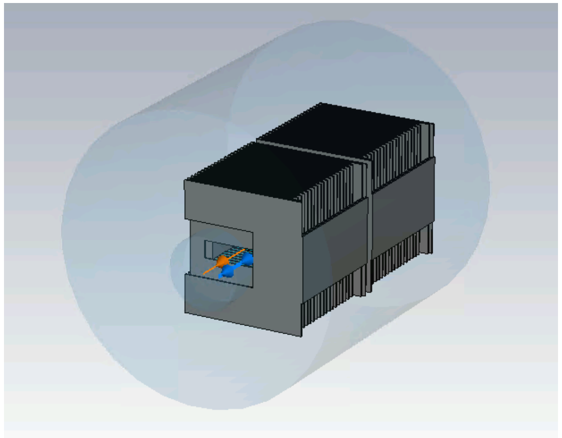




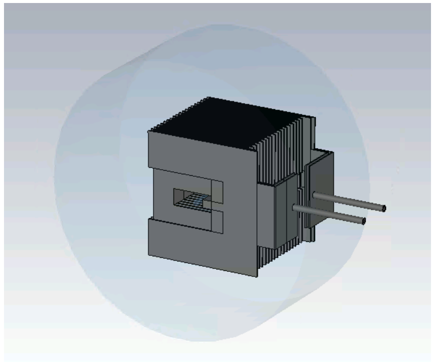
Pictures scanned from negative (Dec. 1981)
https://cds.cern.ch/record/754592

KFH31 - KFH3234 CAD models

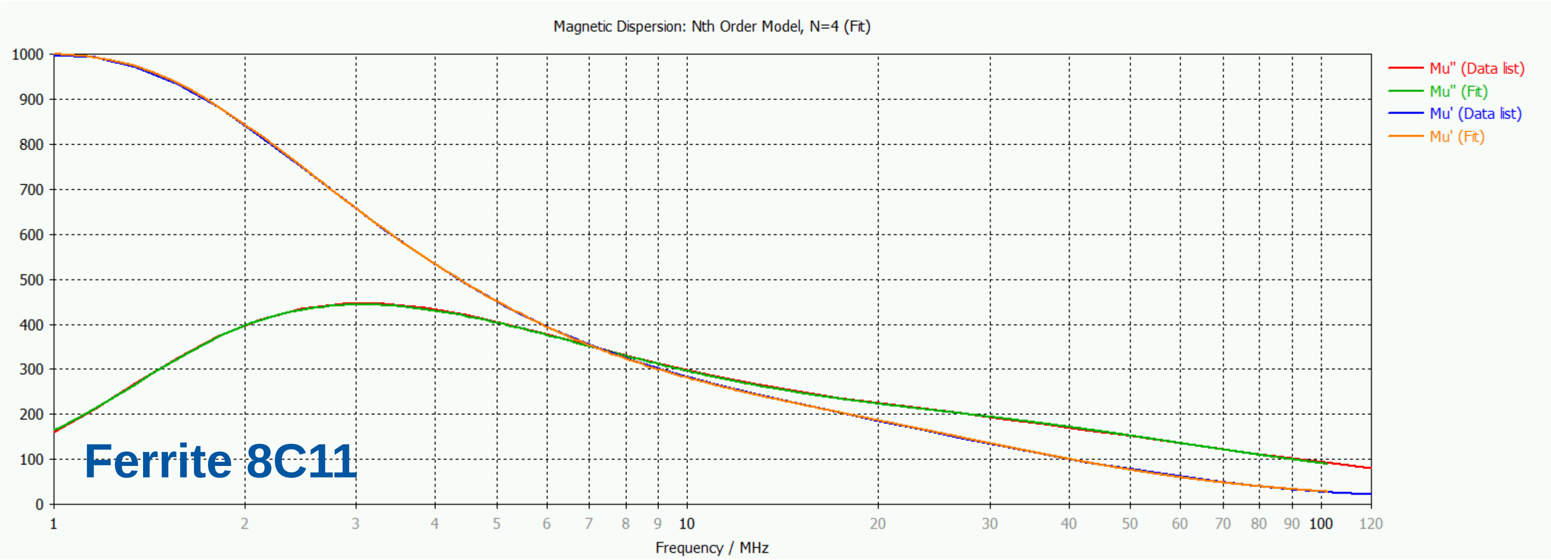
KFH3234

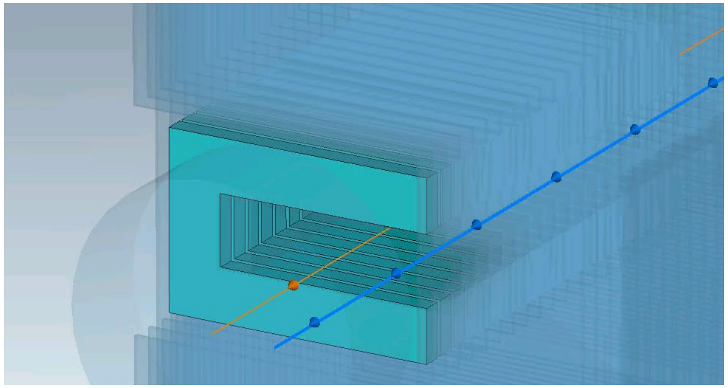


KFH31



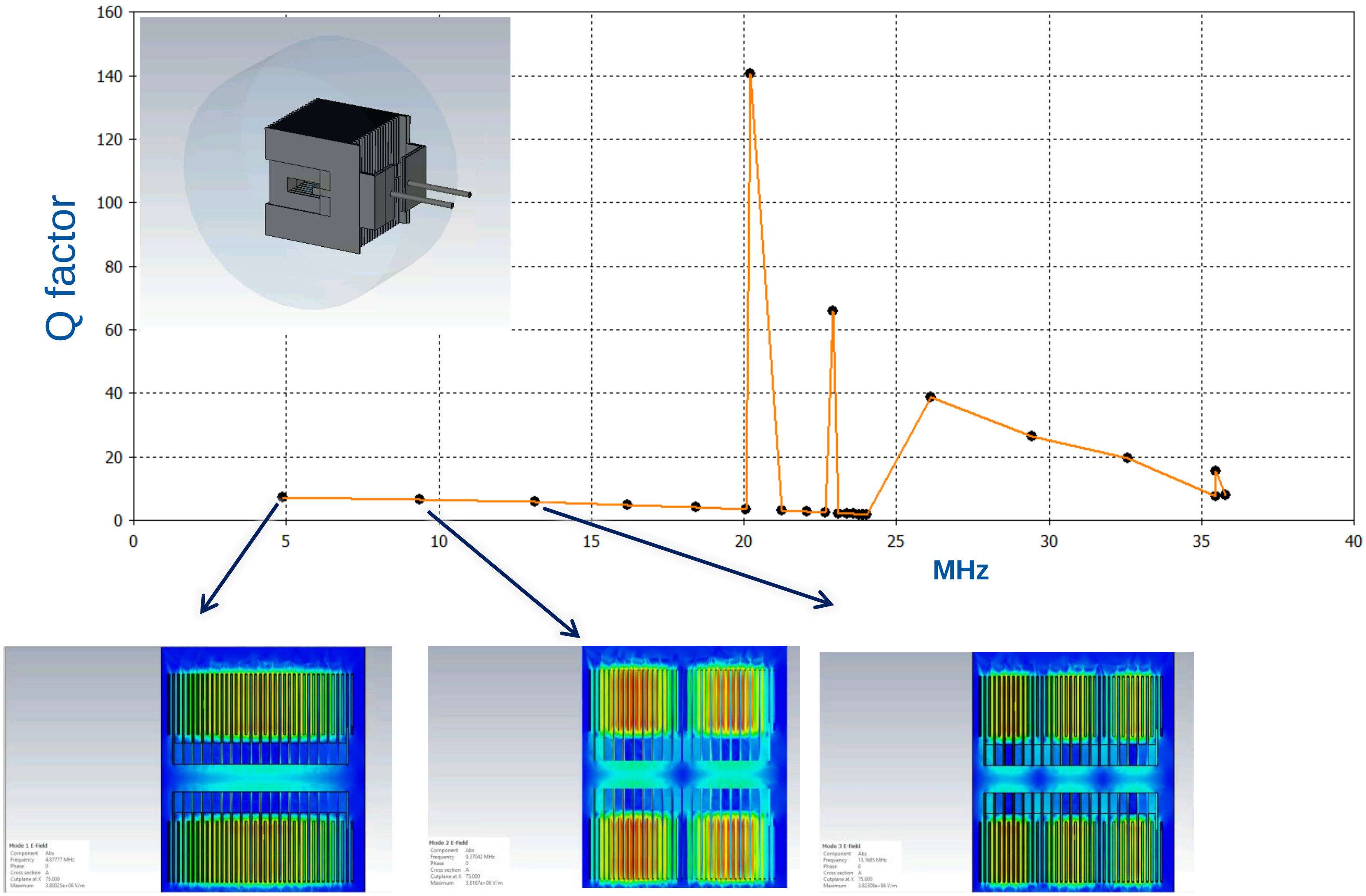
Ferrite material



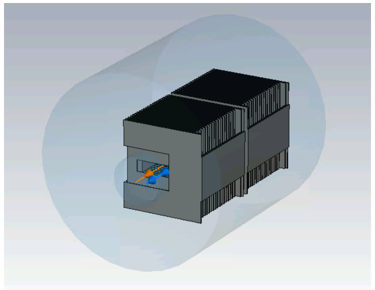


Source:
https://www.ferroxcube.com/upload/media/product/file/MDS/8c11.pdf

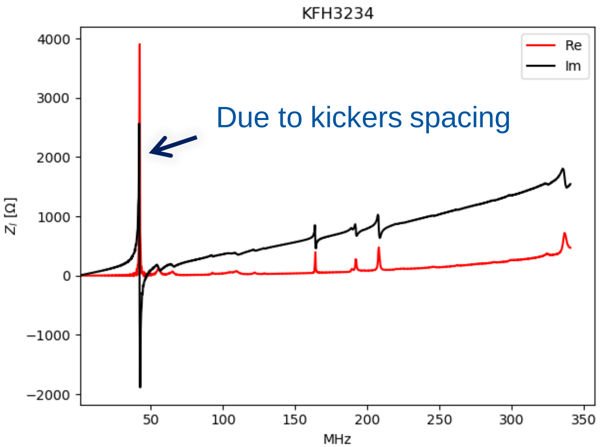
KFH31 Eigenmodes



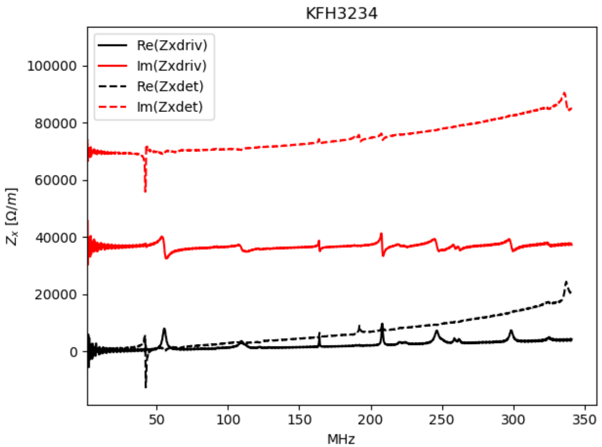
Impedances



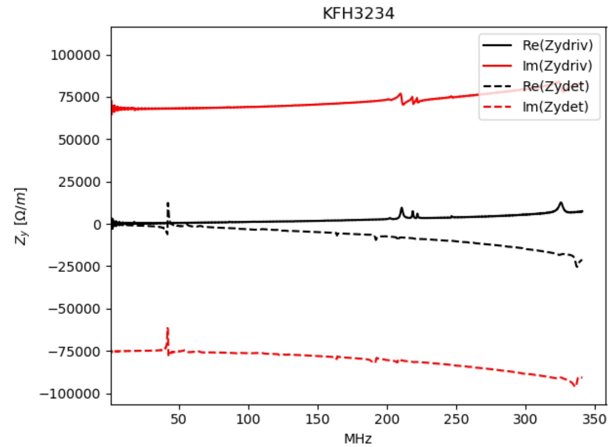
Wakefield simulations of kicker module do not show large transverse modes at the observed frequencies.



Longitudinal



Horizontal

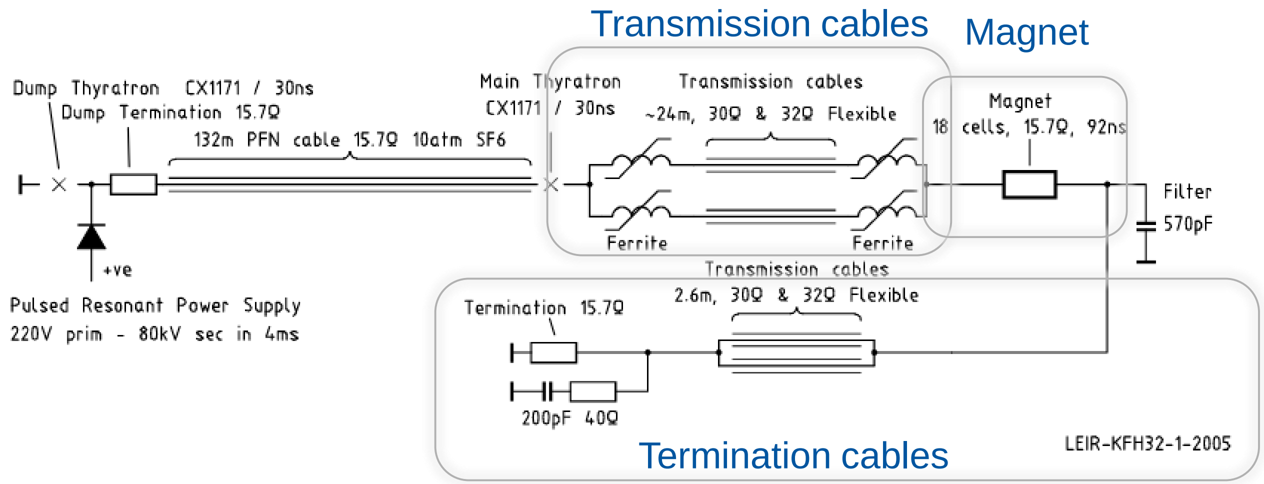


Vertical

Kicker structure can sustain a quasi-TEM mode → cable effect could play a role. We tried also to include the effect of the cables with available information.

Kicker with circuitry

Circuit model available in Design Report.
Pulse Formation Path made of parallel of saturating inductors and TL cables.



Z_c (characteristic cables impedance): 15.7 Ω
L_{sat} (saturating inductors): 10μH series with R_{sat} = 10 $m\Omega$
l_1 (transmission cable length): ~24 m
l_2 (termination cable length): ~2.6 m
Z_k: kicker impedance

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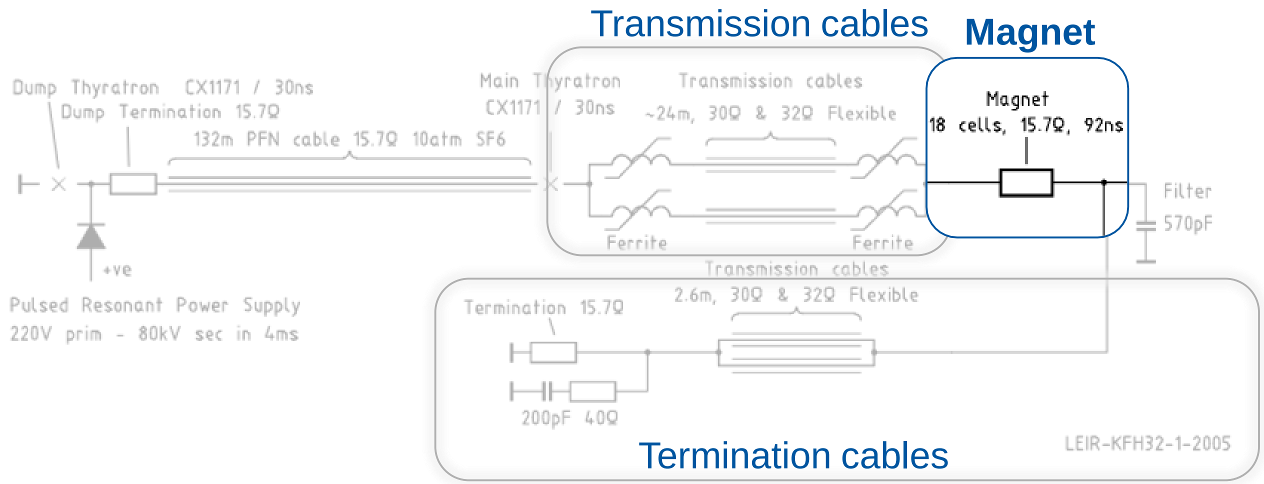

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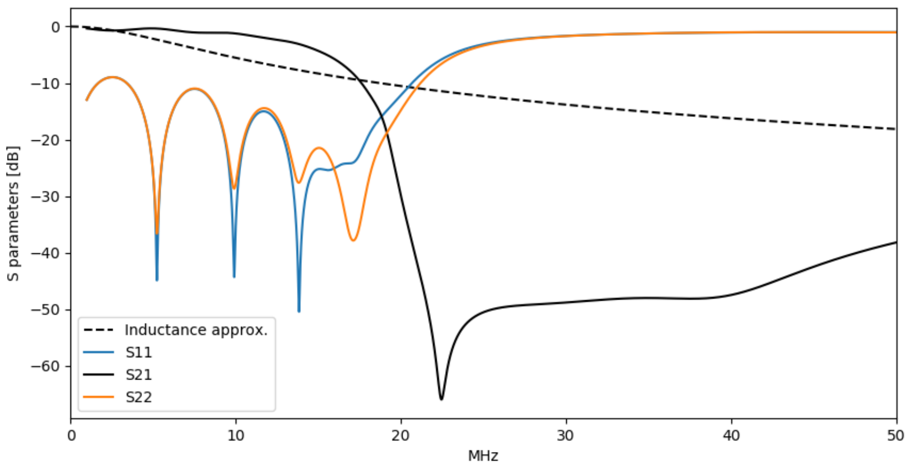
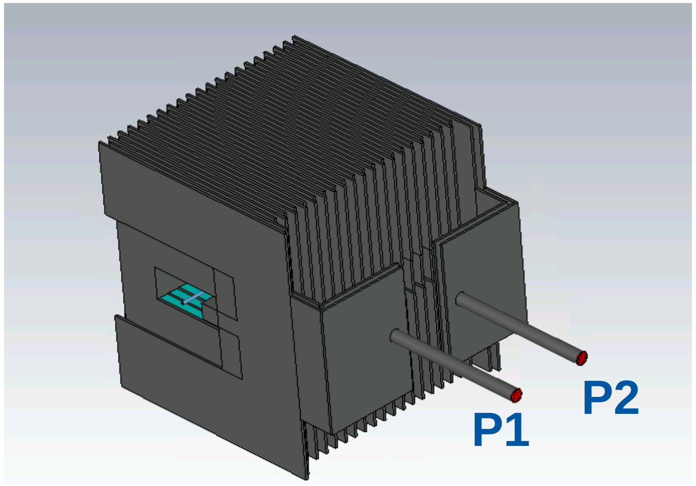
Kicker impedance

Simulated the kicker impedance from P1 to P2

Magnet as series impedance approximation:

$$S21 = \frac{2Z_c}{Z_k + 2Z_c}$$



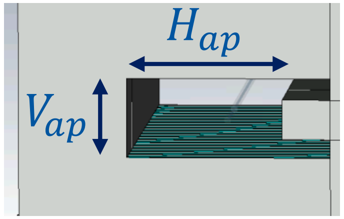


$Z_k \sim j\omega L_{mag}$ with

$L_{mag} \cong \mu_0 \left(\frac{H_{ap}}{V_{ap}}\right) l_{mag} \sim 60nH/cell$

H_{ap}= 170mm

V_{ap} = 66mm

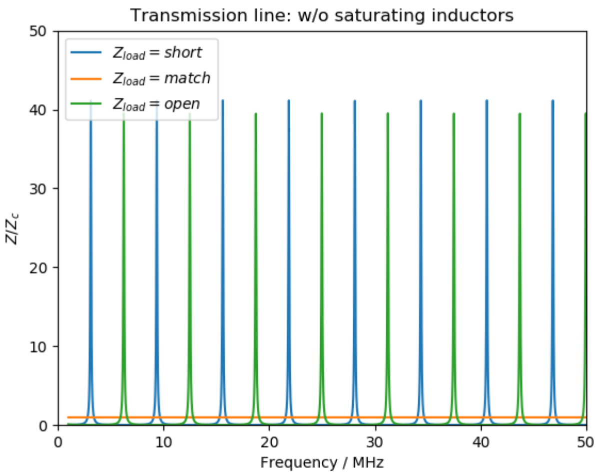


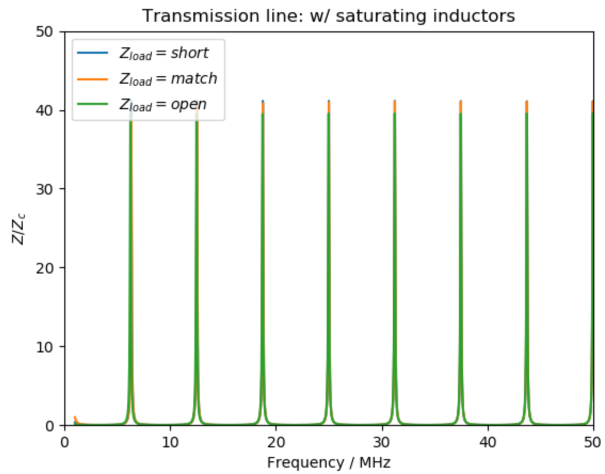
Inductive behavior up to ~20 MHz.

→ RF measurements between P1/P2 would help to cross-check the model!

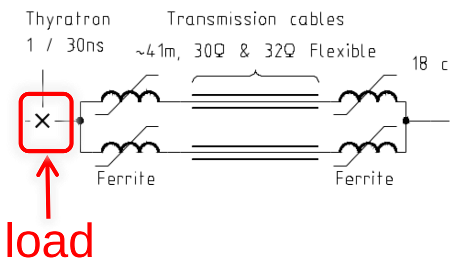
Transmission cables

Transmission side studied for different load (short, match, open).





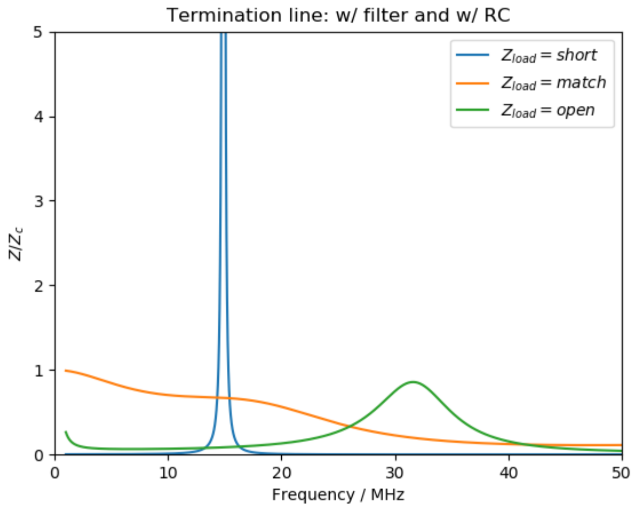
Transmission cables

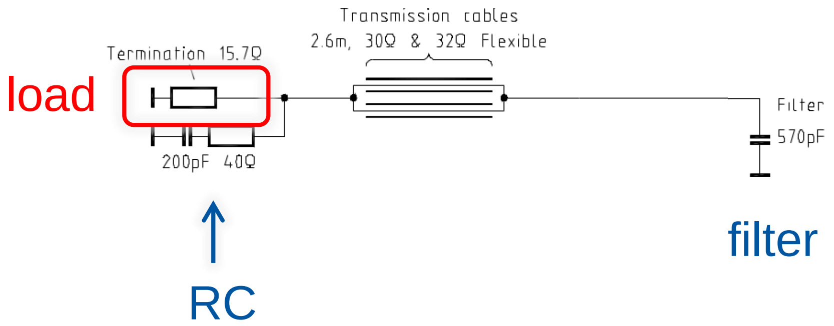


Saturating inductors show large load → dominate response of transmission side

Termination cables

Termination side studied for different load (short, match, open).

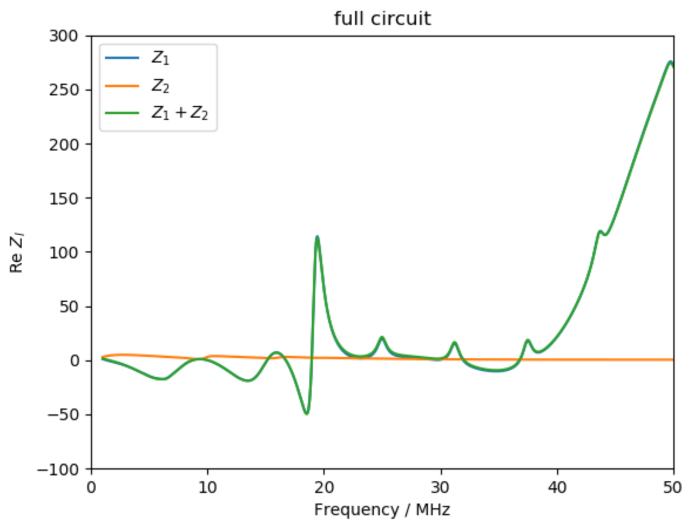


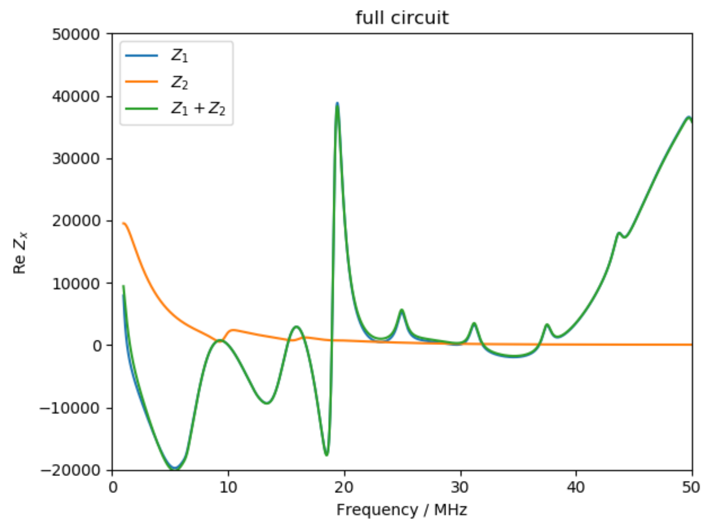


Termination side is normally matched → no issue.
Resonance with short: measurements recommended to benchmark the model

Kicker impedance with circuitry

Computed the effect of both transmission side (Z_1) and termination side (Z_2) with the approach of [1,2,3]:





- A large resonance at 20 MHz between transmission side (Z_1) and magnet is generated.

[1] G. Nassibian and F. Sacherer, Nucl. Instrum. Methods159,21 (1979)
[2] D. Davino and H. Hahn, Phys. Rev. ST Accel. Beams6,012001 (2003)
[3] C.Zannini, G.Rumolo, V.G.Vaccaro, CERN-ATS-2012-134, Particle Accelerator Conference(IPAC'12) –May20-25, 2012, N. Orleans, USA

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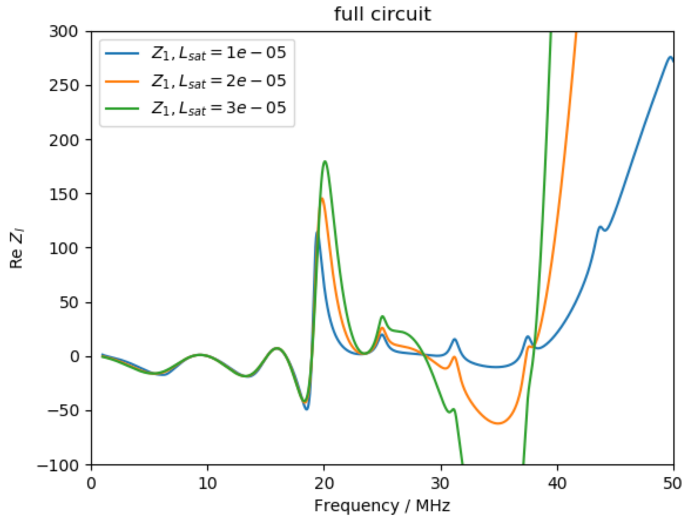

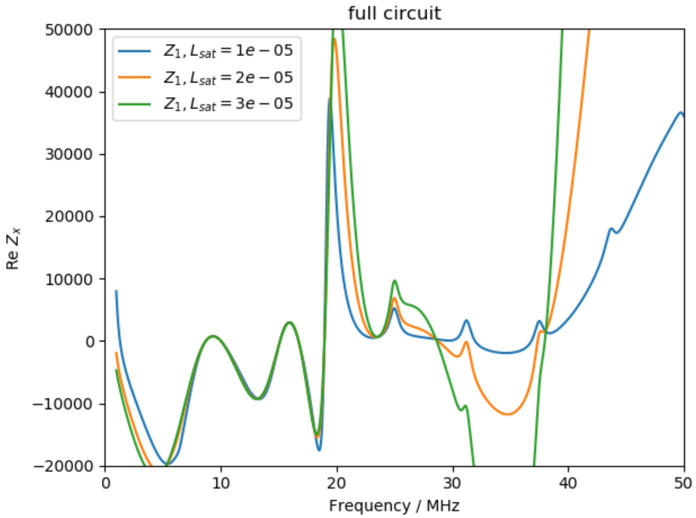

- A large resonance at 20 MHz between transmission side (Z_1) and magnet is generated.
- Largely dependent on the saturating inductance value.

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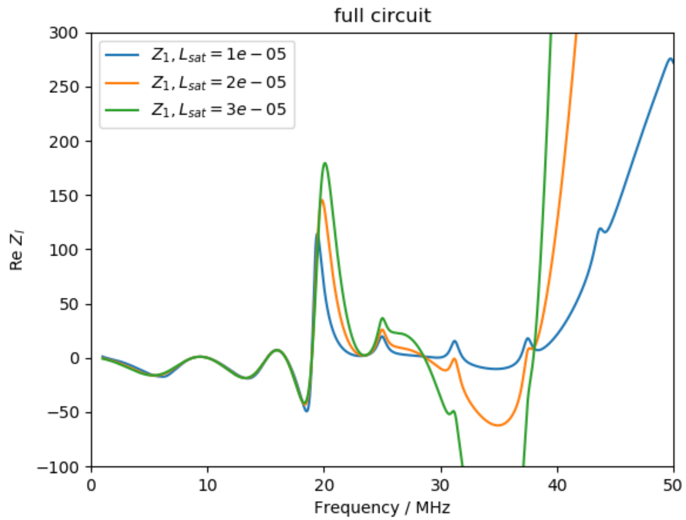
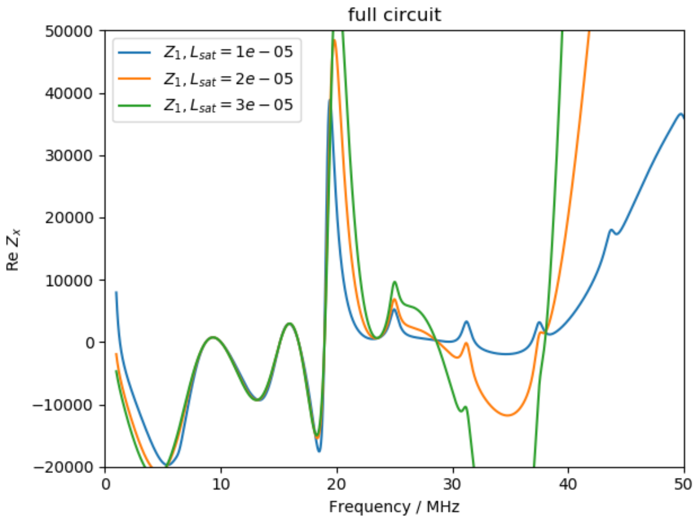




- A large resonance at 20 MHz between transmission side (Z_1) and magnet is generated.
- Largely dependent on the saturating inductance value.
- Negative impedance unphysical → maybe related to the magnet approximation as a simple series impedance.
- Benchmark with CST co-simulation wished/in progress.

[1] G. Nassibian and F. Sacherer, Nucl. Instrum. Methods159,21 (1979)
[2] D. Davino and H. Hahn, Phys. Rev. ST Accel. Beams6,012001 (2003)
[3] C.Zannini, G.Rumolo, V.G.Vaccaro, CERN-ATS-2012-134, Particle Accelerator Conference(IPAC'12) –May20-25, 2012, N. Orleans, USA

CERN

Summary and conclusions

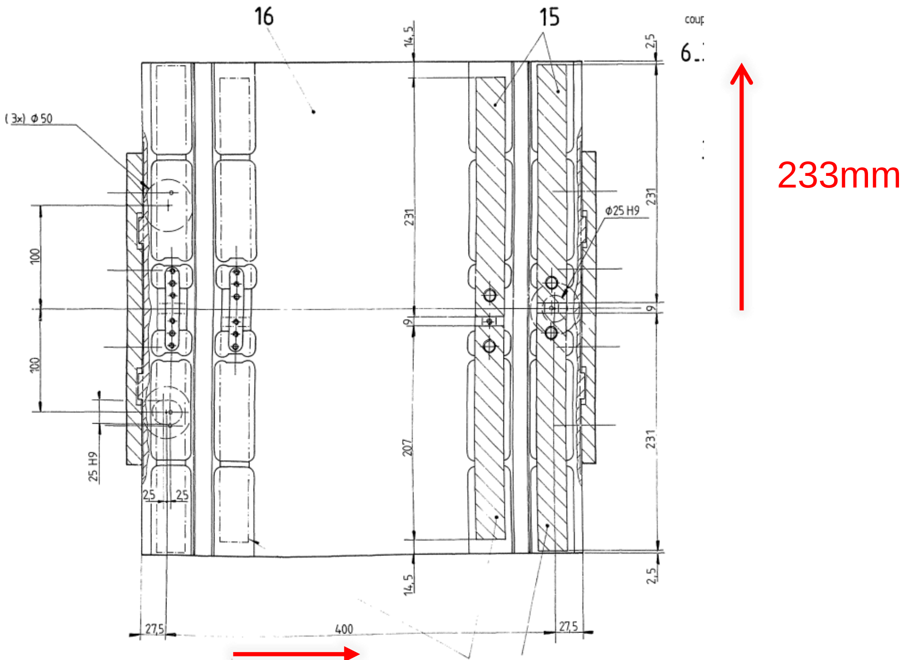
- KFH31 and KFH3234 kickers were studied from the impedance and coupling to circuitry point of view.
- Kicker CAD module made from drawings and pictures: might present several kind of approximations.
- The kicker impedance related to core losses was computed → no strong transverse resonance observed.
- The kicker's cables effect was computed → a resonance at 20 MHz present:
    - Some unphysical behavior of impedance may be related to the magnet approximation as a simple series impedance.

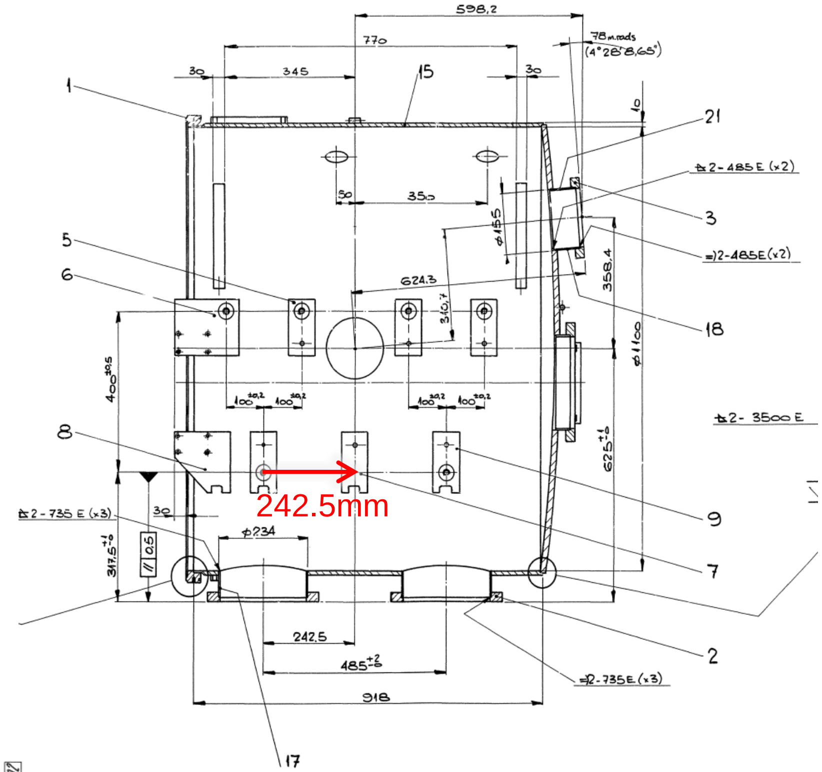
Next:

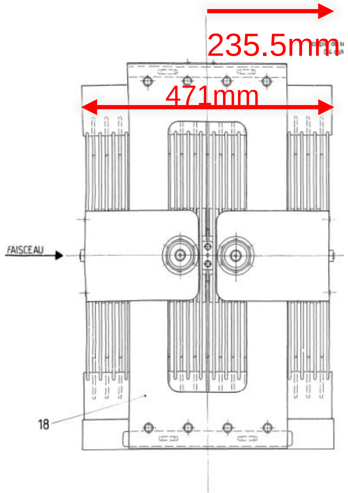
- RF measurements on kicker and cables to be discussed/planned with experts.
- CST co-simulation of kicker magnet + RF circuits.

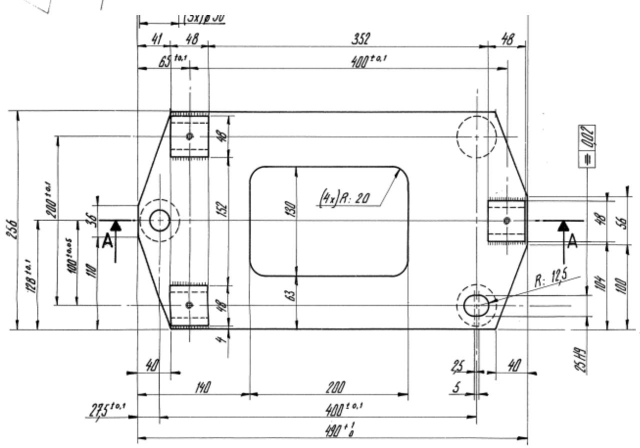
Appendix

Original drawings

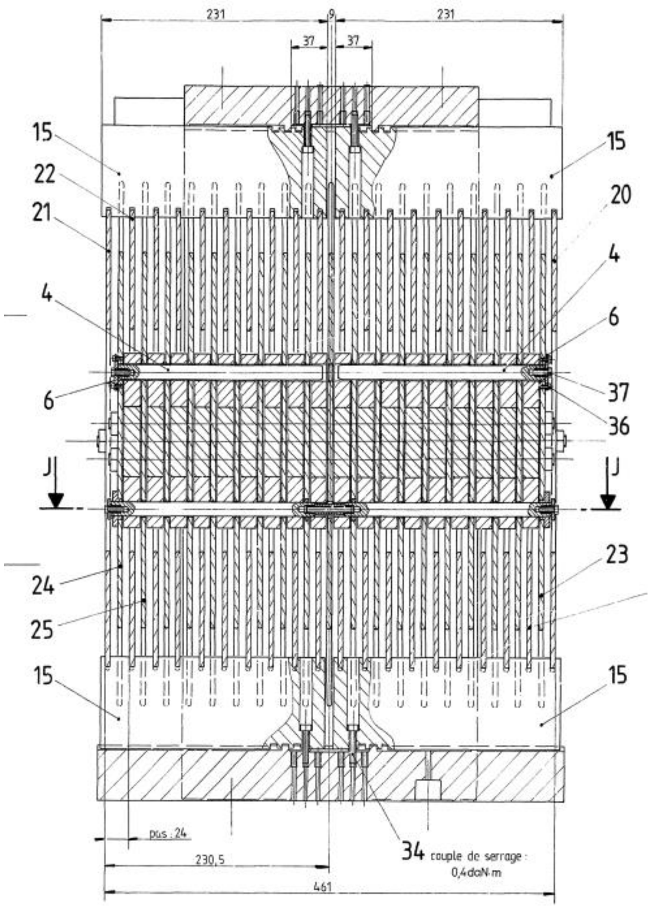






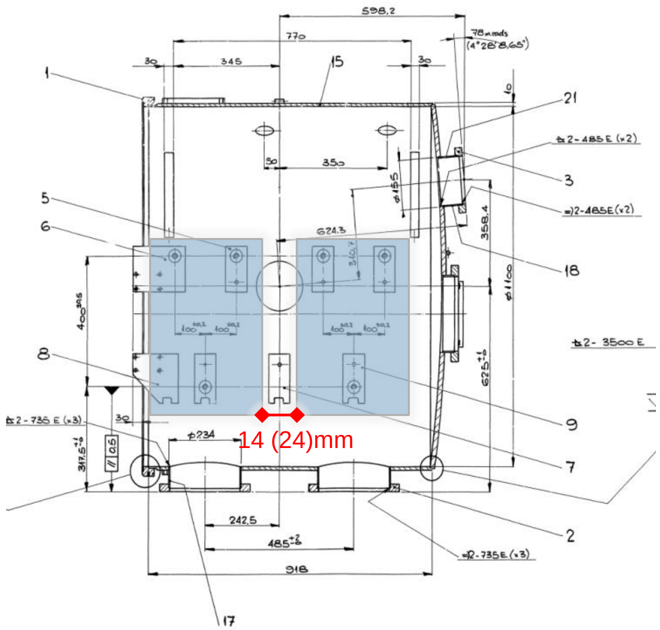


Details on module spacing



471mm full length (235.5 half)
461mm plate-to-plate (230.5 half)

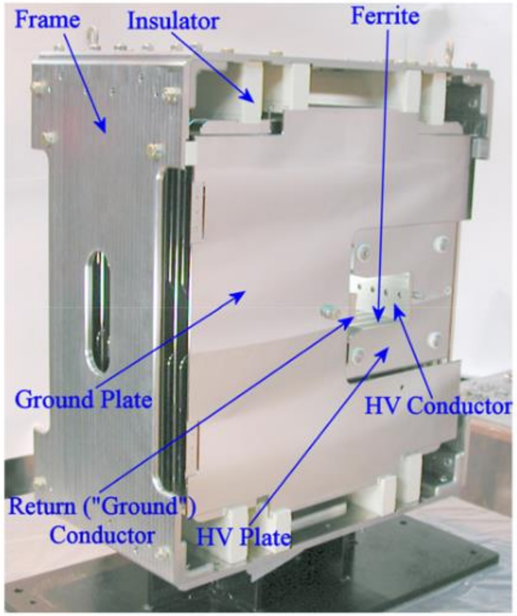
Module distance 7mm full module to middle
12 mm plate to middle

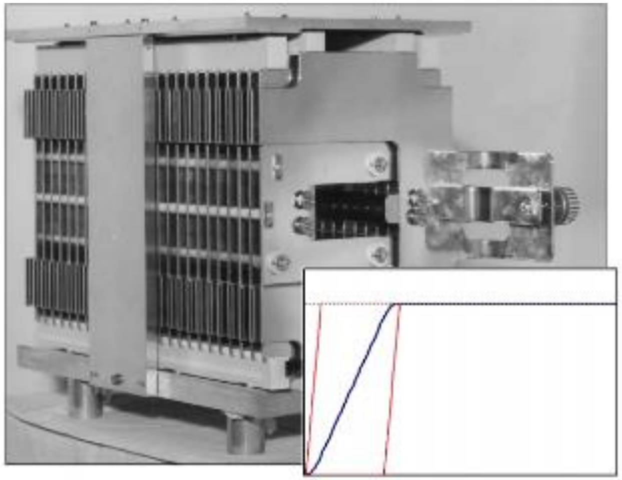


Some references on kickers

M.Barnes "Injection and extraction magnets: kicker magnets " CAS 2009: Specialised Course on Magnets, Bruges, 16-25 June 2009

L.Ducimetière, "Advances of transmission line magnets", Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee.





RF networks: series impedance

$$b_i = \frac{U_i - I_i Z_0}{2\sqrt{Z_0}}$$

$$a_i = \frac{U_i + I_i Z_0}{2\sqrt{Z_0}}$$

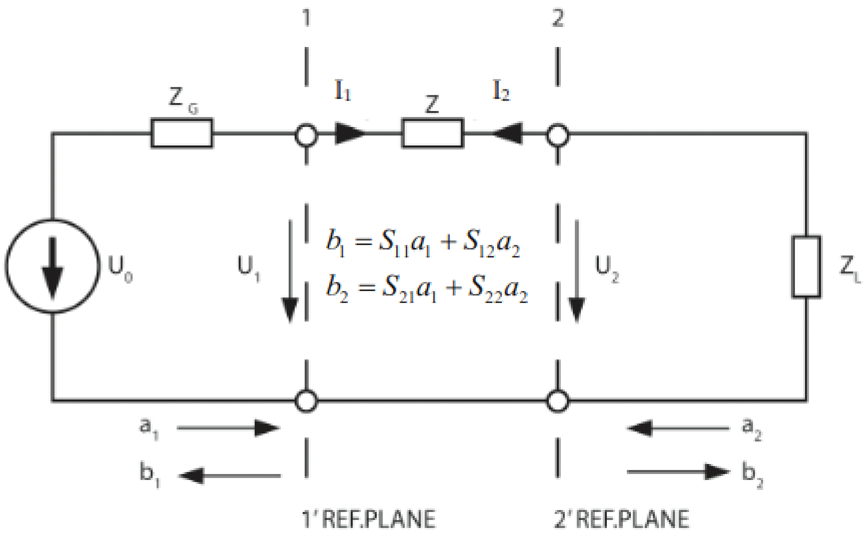


Fig. 1: Example for a 2-port network: a series impedance Z

$$\left.\frac{b_2}{a_1}\right|_{a_2=0} = \frac{U_2 - I_2 Z_0}{U_1 + I_1 Z_0}$$

$$U_2 = U_0 \frac{Z_0}{2Z_0 + Z} \qquad I_2 = -I_1 = -U_0 \frac{1}{2Z_0 + Z}$$

$$\left.\frac{b_2}{a_1}\right|_{a_2=0} = \frac{U_0 \frac{Z_0}{2Z_0 + Z} + U_0 \frac{Z_0}{2Z_0 + Z}}{U_0 \frac{Z + Z_0}{2Z_0 + Z} + U_0 \frac{Z_0}{2Z_0 + Z}} = \frac{2Z_0}{Z + 2Z_0}$$

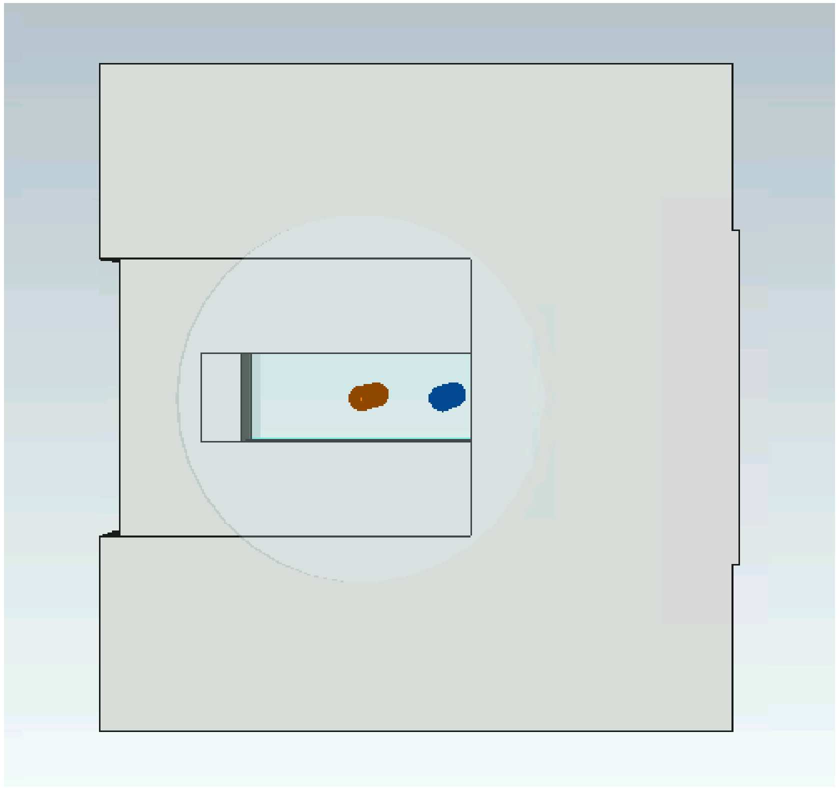
$$\left.\frac{b_1}{a_1}\right|_{a_2=0} = \frac{U_1 - I_1 Z_0}{U_1 + I_1 Z_0}$$

$$U_1 = U_0 \frac{Z + Z_0}{2Z_0 + Z} \qquad I_1 = U_0 \frac{1}{2Z_0 + Z}$$

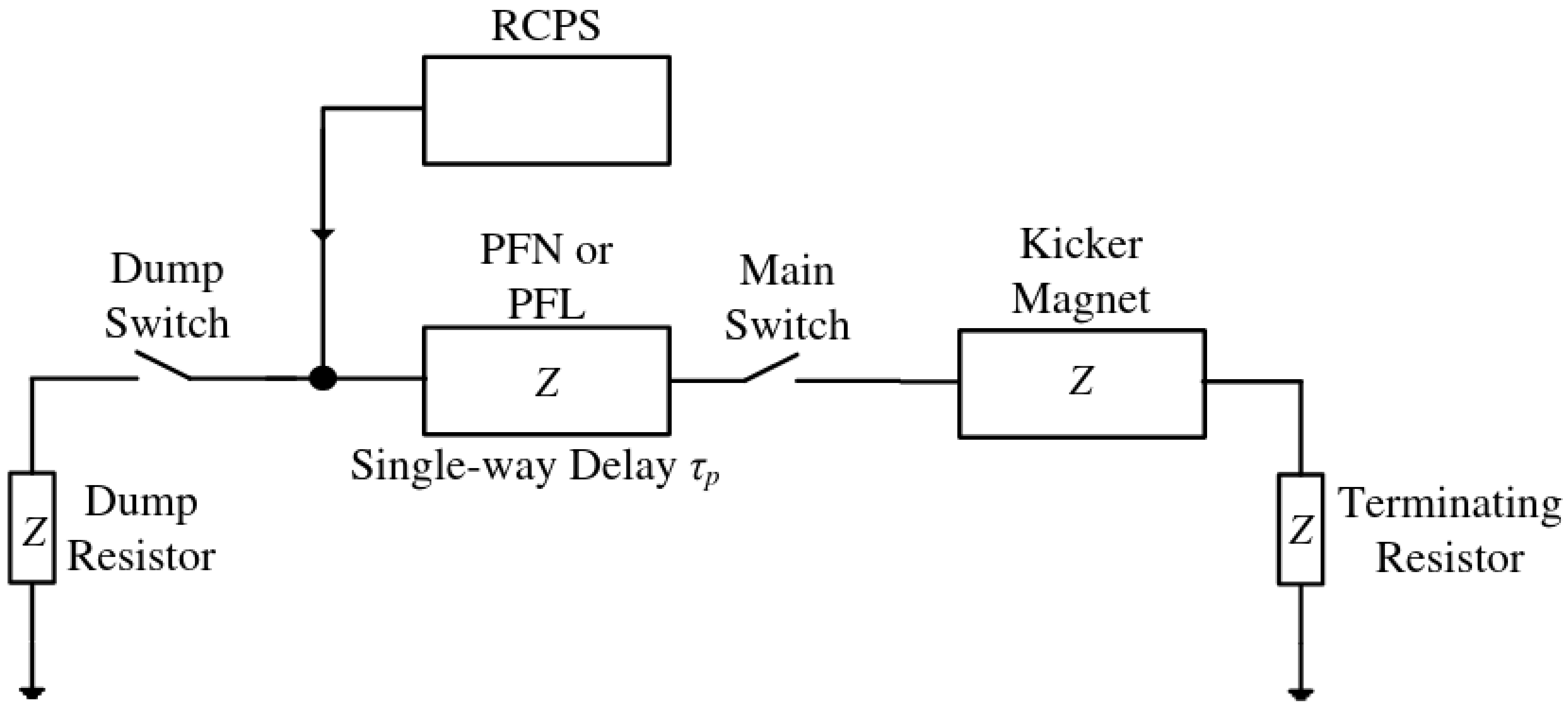
$$\left.\frac{b_1}{a_1}\right|_{a_2=0} = \frac{Z}{2Z_0 + Z}$$

https://cds.cern.ch/record/1415639/files/p67.pdf

KFH3234 front view



A simplified kicker schematic



T.Kramer, “Kickers, Septa and Protection Elements”, CAS2018
https://indico.cern.ch/event/683936/contributions/2803312/attachments/1564570/2691879/Kickers_and_Septa_2018_CAS_ESI.pdf

Kicker circuit model for impedance

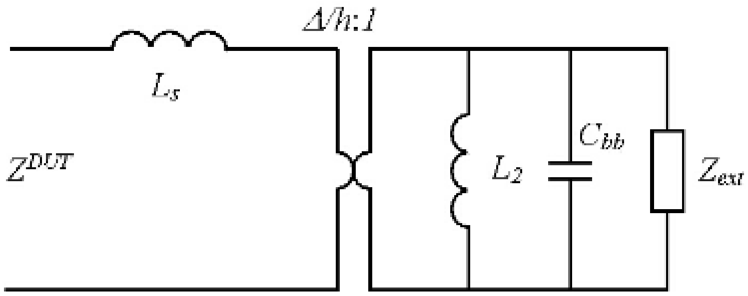


FIG. 2. Equivalent circuit for Z^{DUT}.

$$Z_l = \frac{1}{4} \frac{Z_k Z_g}{Z_k + Z_g}$$

$$Z_x = \frac{c}{\omega\,(H_{ap}/2)\text{^}2} Z_l$$

https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.6.012001