CERN

A Versatile Wideband RF System Design

M.Paoluzzi – BE-RF

Same Basic Numbers from RF Point Of View

- Synchrotrons for Hadron Therapy typical energies :
  - Injection at few MeV
  - Extraction at few hundreds MeV

  Particles' β substantial increases from injection to extraction

- Beam revolution frequency :
  - Injection at few hundreds of kHz
  - Extraction at few MHz (10-20 MHz for small machines)

  Large frequency range $f_{ext}/f_{inj} \approx 10$ or higher

- For slow cycling machines required voltage are few kV (tens of kV or RCS)

Modern Magnetic Alloys

Modern Magnetic Alloys (MA) are now of common use for RF cavities up to 10 – 20 MHz.
Among others :

- Vitrovac from Vacuumschmelze (CNAO)
- Nanoperm from Magnetec (GSI)
- Finemet from Hitachi Metals (CERN, MedAustron, J-PARC)
- FS from Toshiba (HIMAC)

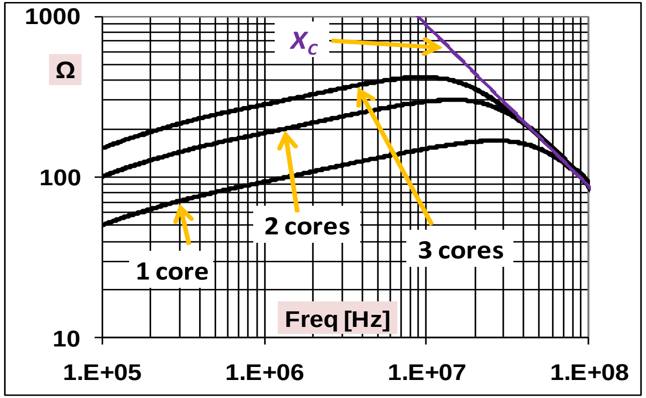
All MA exhibit a low quality factor allowing wideband operation → no tuning

Saturation and Curie temperature are substantially higher than for ferrite → higher acceleration gradient

Basic Cell : Basic Choices

New RF system for the CERN PS Booster RF upgrade project

Design to replace the three existing ones (C02, C04 and C16) → 0.6 to 18 MHz

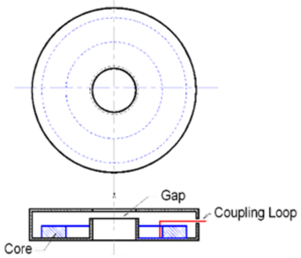


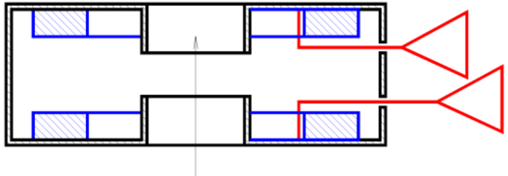
Selected material Finemet® FT3L

At low and mid frequency, stacking more cores across a gap proportionally increases the total impedance.

At high frequency the response is mainly limited by the structure capacitance that becomes effective earlier.

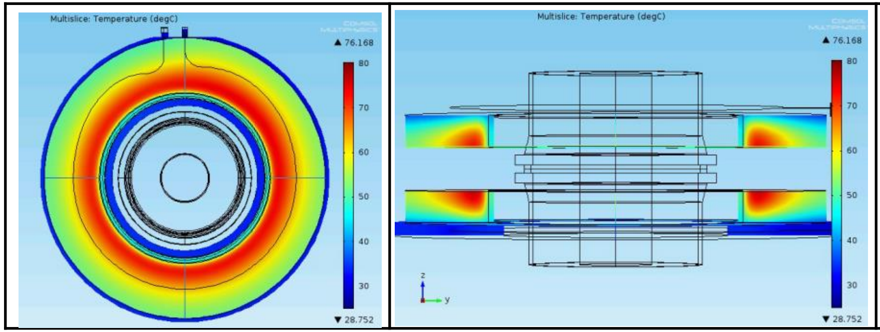
Full exploitation of wideband characteristics when using a single core or one on each side of the gap driven in push-pull.



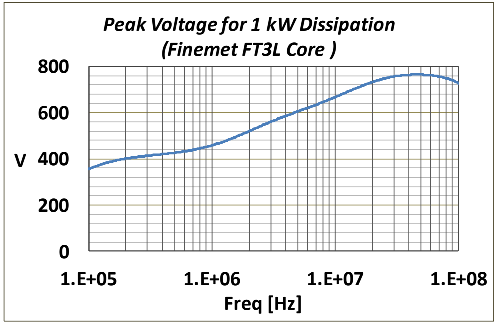


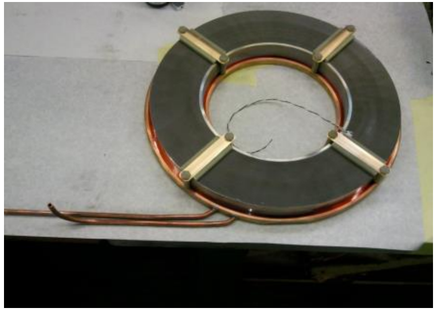
Basic Cell : *Dimensions, Cooling, RF Voltage*

Core dimensions dictated by PS Booster limitations : 330/200/25 mm.
Indirect water cooling selected.



750 W
Water T_{in}=18 ˚C
Water T_{out}=33 ˚C
3 litres/min





Assuming 100°C maximum in the core one ring can dissipate 1 kW.

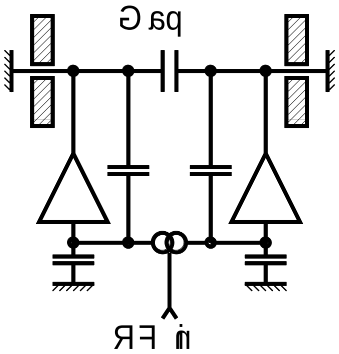
From measure RF losses, a two cores cell can provide 0.7 - 1.5 kV_{PK} in the frequency range 0.1 - 100 MHz.

This power level can be provided by a compact solid-state amplifier.

The cell longitudinal length is 130 mm.

Basic Cell : *RF Power Amplifier*

- Best RF performances achievable with the RF Power amplifier placed near by the load.
- Single box (H323/D295/W120 mm) containing two 1.6 kW power stages with common drive.
    - Push-pull version with two 2 x 1.6 kW outputs
    - Single-ended version with single 3.2 kW output
- Operation frequency 0.1 MHz to 70 MHz (limited power above 10 MHz).
- Plug-in unit.
- Peculiar configuration selected to minimizes complexity and allow implementation of fast RF feedback.
- Radiation tolerant devices and design including radiation effects compensation.
- De-rated use of power devices, built-in redundancy and reserves

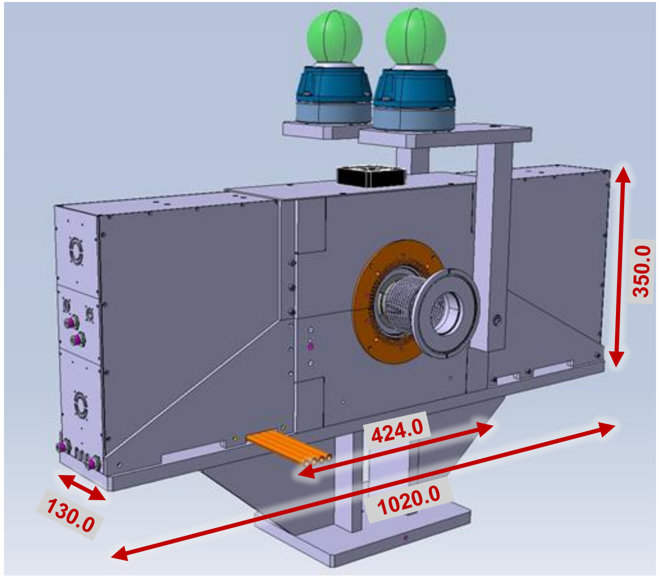


Basic Cell : Layout and response

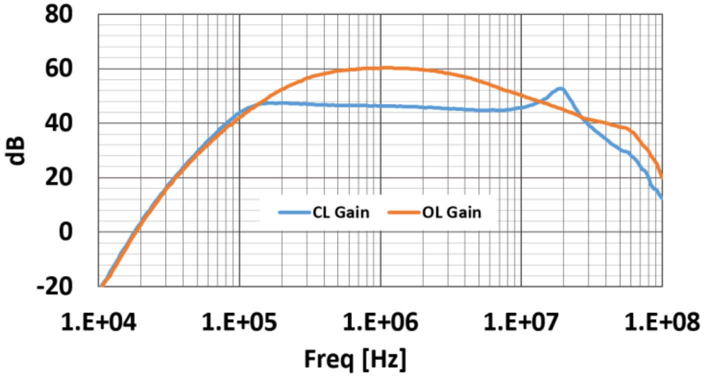
- Operation from 100 kHz to 20 MHz
- With Push-Pull amplifier:
  - 800 V_{PK} from 0.5 MHz to 5 MHz (limitations outside this range)
- With Single-Ended amplifier on each side
  - 1 kV_{PK} from 0.5 MHz to 10 MHz (limitations outside this range)
- Optional fast RF feedback loop gain (PP amplifier).
- Gap voltage monitor
- Gap relay

Cell layout and dimensions

Central Resonator with amplifier emplacement on each side



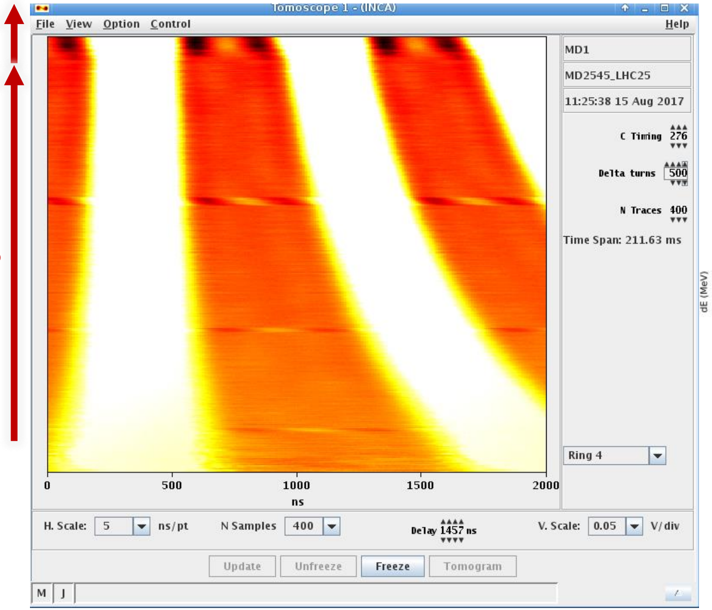
Cell frequency response with and without fast RF feedback loop (Push-Pull amplifier)



Basic Cell : *Multi-harmonic operation*

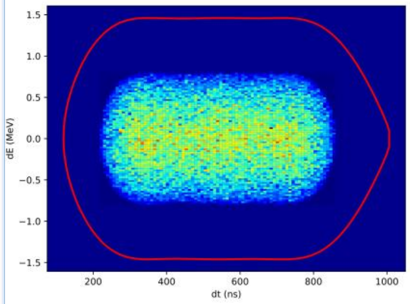
h1+h2

h1+h2+h3



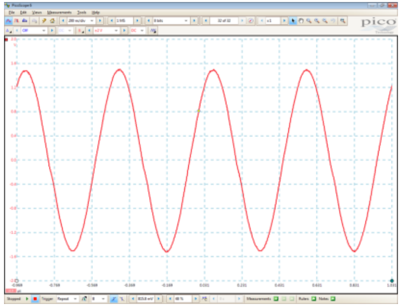
Courtesy S. Abright

h1+h2+h3

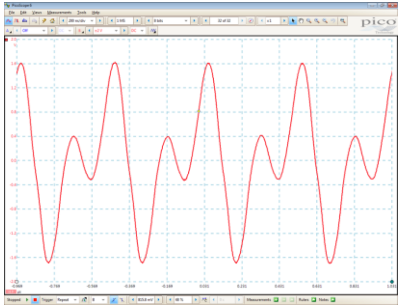


Courtesy S. Abright

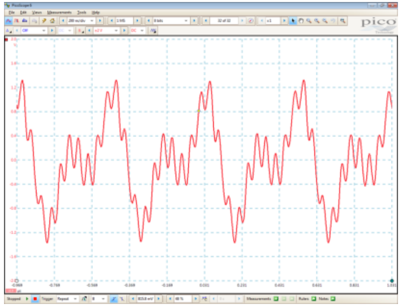
h1



h1-+h2



h1+h2+h10



Application : CERN PS Booster

Frequency range : 0.6 to 18 MHz

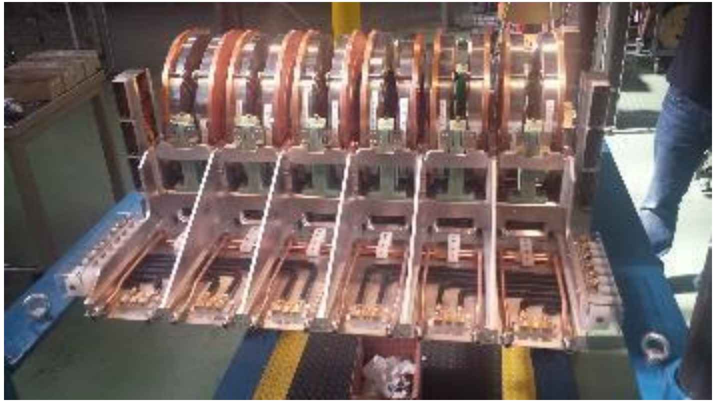
Total nominal voltage : 22 kV (Max 28 kV)

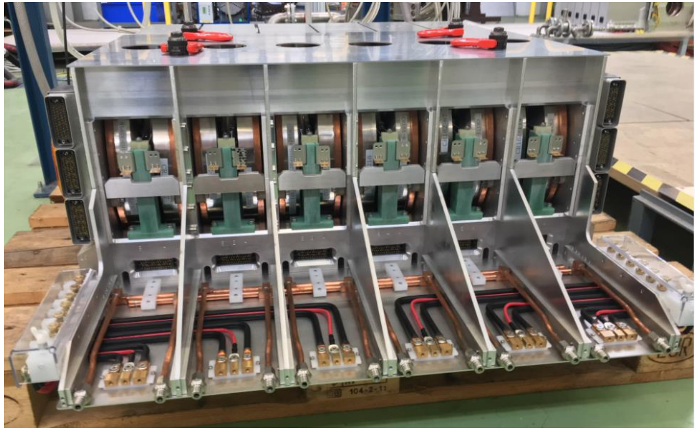
Cell voltage : Nominal 610 V

One Push-Pull amplifier per cell

36 cells in groups of 6 per ring

144 cells total in the machine





Application : CERN AD

Frequency range : 0.174 to 3 MHz

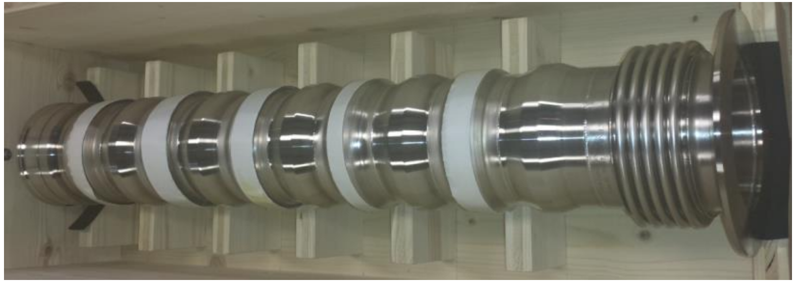
Total nominal voltage : 3 kV

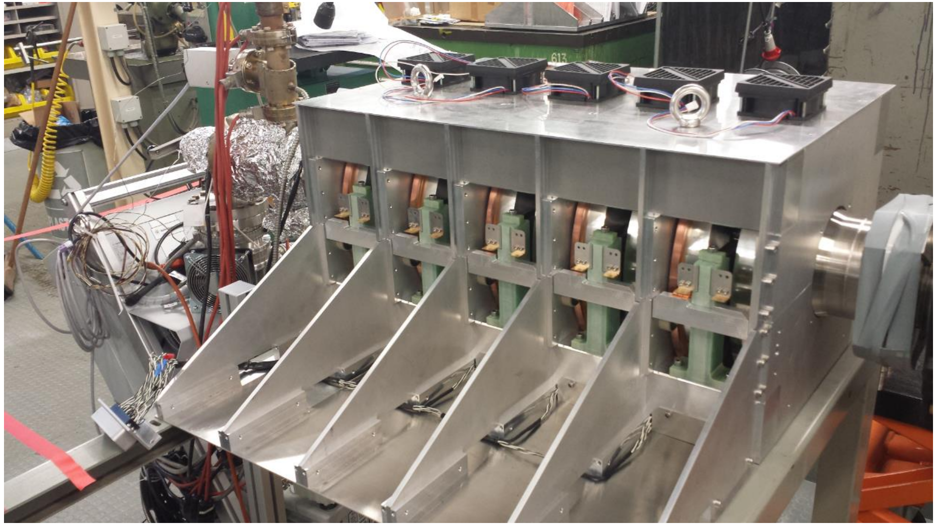
Cell voltage : Nominal 600 V (Max 800 V)

One Push-Pull amplifier per cell

Group of 5 cells

(Re-use of PSB Prototype system)





Application : ELENA

Frequency range : 0.15 to 2.3 MHz

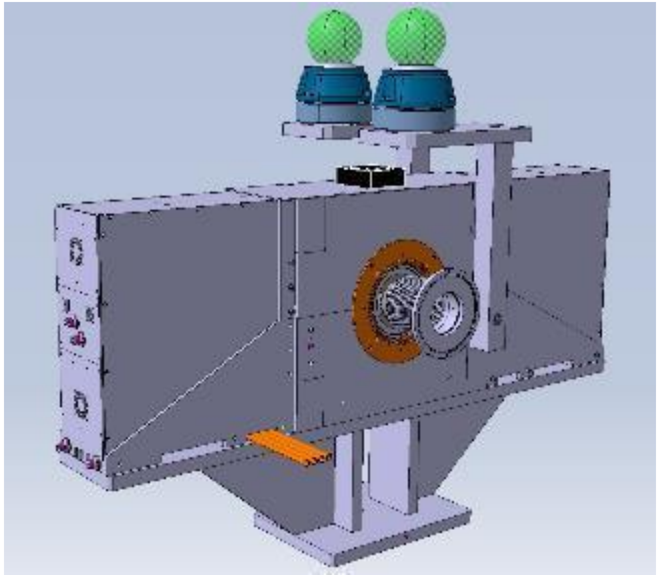
Total nominal voltage : 500 V above 500 kHz (Max 800 V)

100 V below 500 kHz

One Push-Pull amplifier

Single cell

Special vacuum chamber (bakeable)



Application : PS Longitudinal Damper

Frequency range : 0.45 to 10 MHz

Total nominal voltage : 5 kV

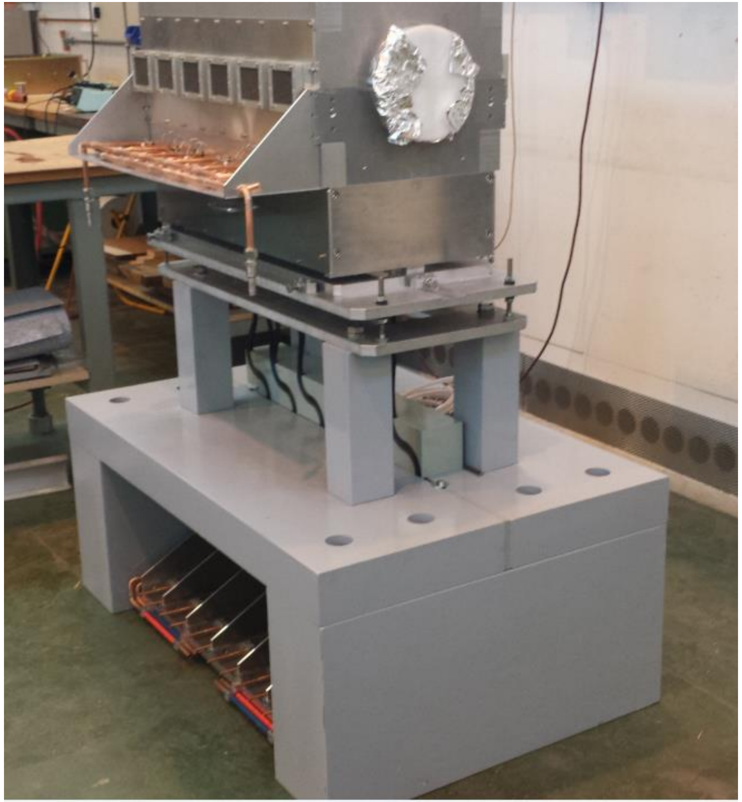
Cell voltage : Nominal 830 V (Max 1000 V)

Two Single-Ended amplifiers per cell

Group of 6 cells

Displace RF Power Amplifier (radiation shielding)

Doubled RF Power (two amplifiers per cell)



Conclusion

- **Modern Magnetic Alloys are nowadays a natural choice for low-medium energy synchrotron RF systems**
- **Wide frequency ranges can be covered without tuning**
- **Can be driven by solid-state amplifiers**
- **The configuration approach (maximum bandwidth, solid-state amplifier) proved very flexible at CERN**
- **The system seems also adapted for medical synchrotrons.**

Thank you for your attention