Elettra Sincrotrone Trieste

Reflective vs Reflectionless RF filters in BPM front ends

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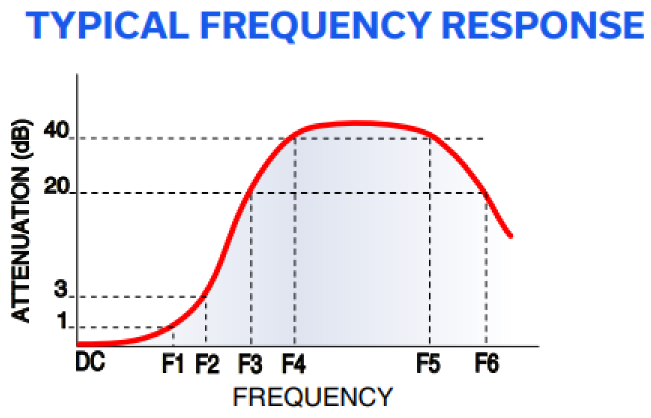
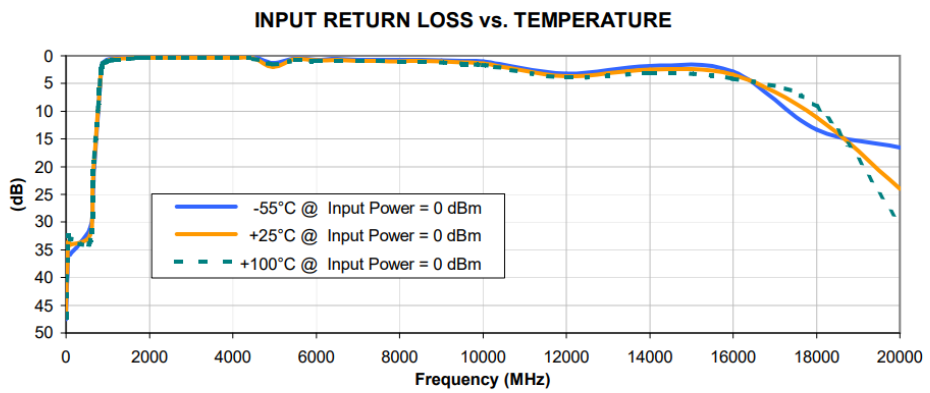
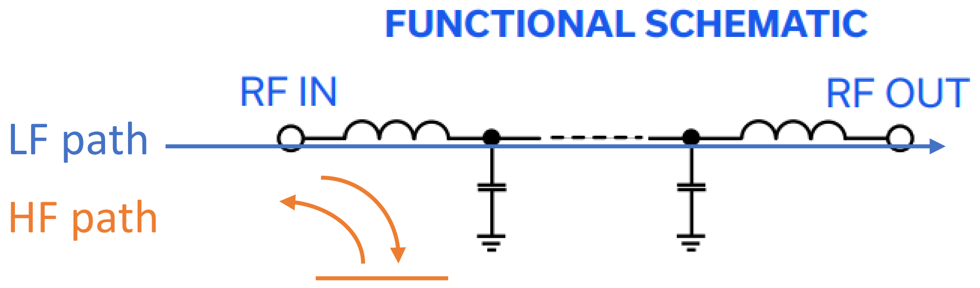
Traditional RF filters

- Traditional filter designs employ circuits which reject undesired signals by reflecting them back to the source
- Simple example: lowpass lumped LC filter
- Stopband signals (above cutoff frequency) are sent back to the source: shunt capacitor is a short circuit
- Different reflection coefficients (S11) for every frequency
- There is no “dissipative” element

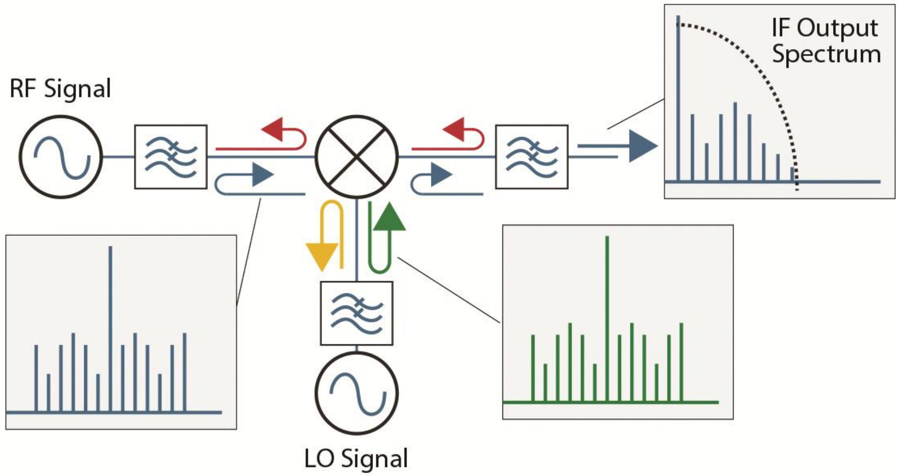






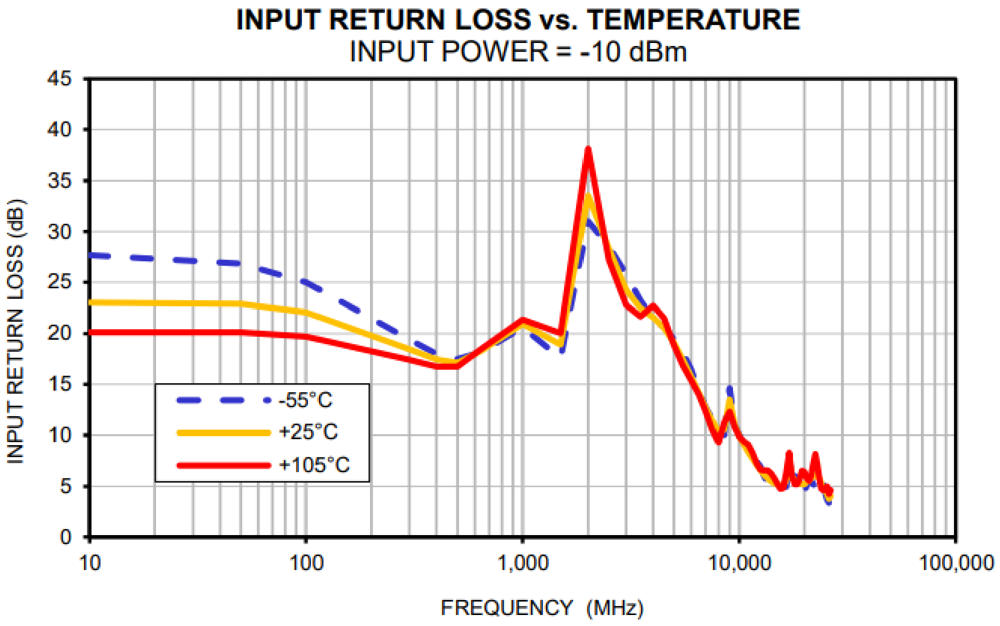
Traditional RF filters

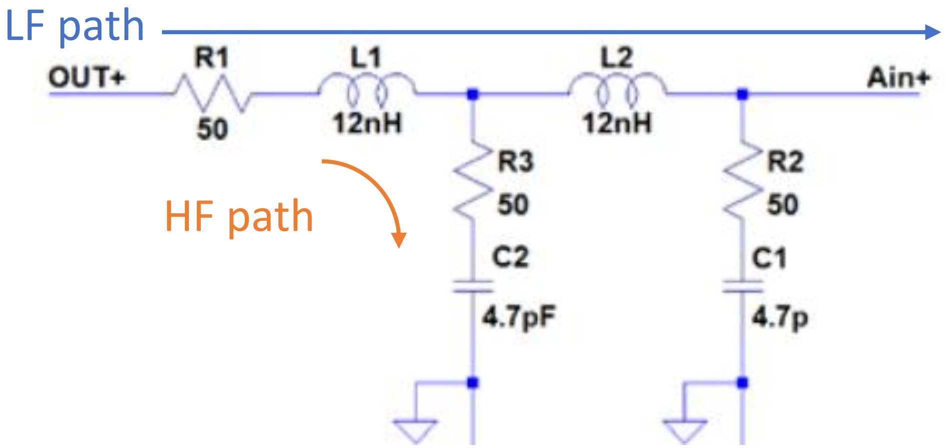
- Advantages:
  - Well-known design methodology
  - Reduced number of components
- Disadvantages
  - Stopband energies are travelling back to the source
  - If the latter is an active component (amplifier, ADC) or a mixer, degradation of SFDR/IMD can occur



Reflectionless (absorptive) filters

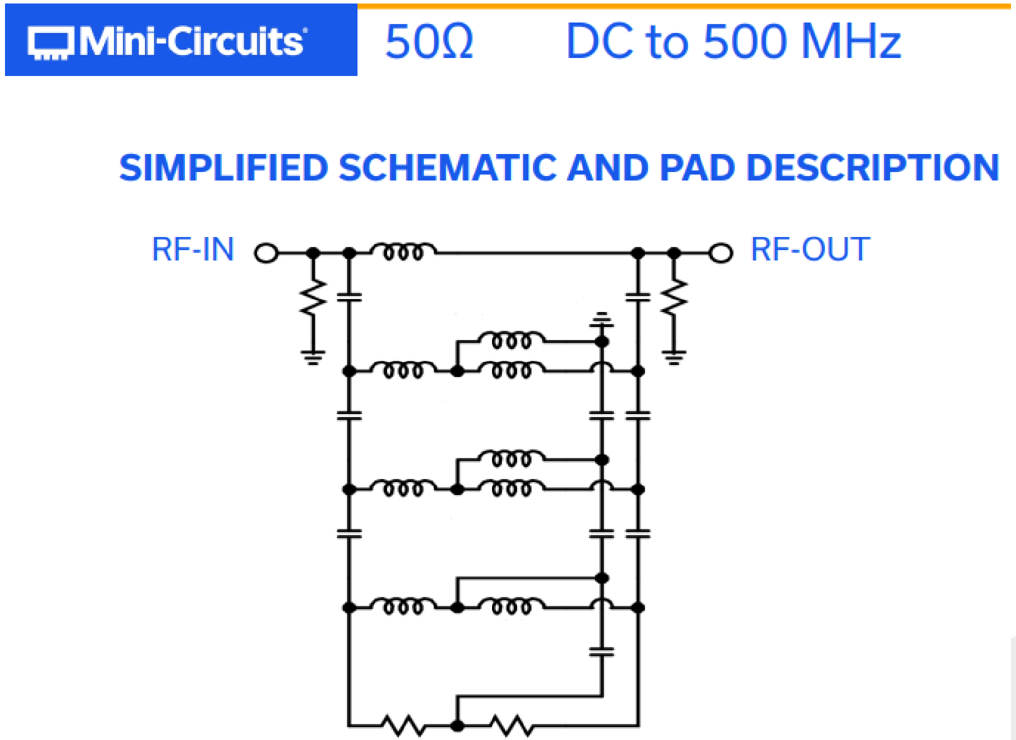
- Stopband signals are dissipated inside the filter itself
- Different paths assure energy absorbing by resistors
- Reduced reflection coefficients for unwanted frequencies
- “flat” S11 parameter

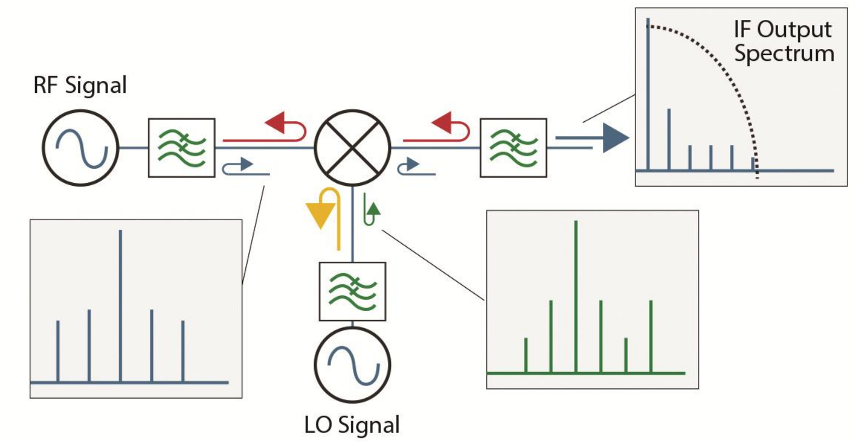




Reflectionless (absorptive) filters

- Advantages:
  - SFDR / IMD increased, as well as linearity
  - Reduced power consumption for some amplifier classes
- Disadvantages
  - More components involved
  - Complex design
  - Resistors can increase in-band noise





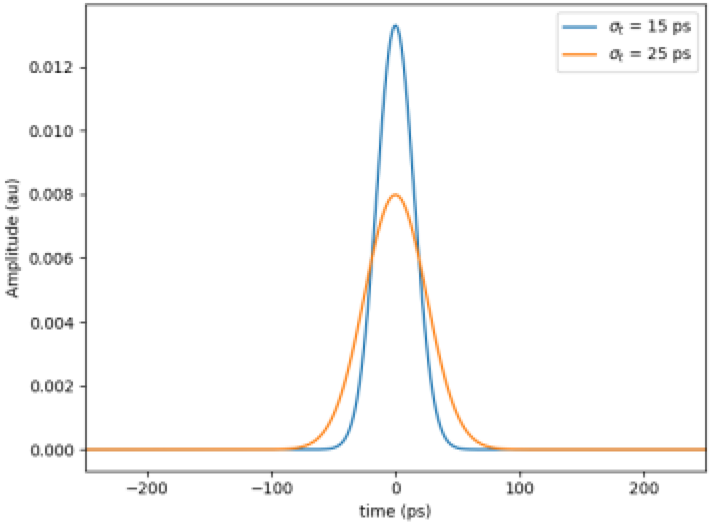
Applications

- Telecomunications, digitizers
- BPM electronics -> is a narrowband AM digital radio
- Lowpass and bandpass filters inside analog front end / input stage
- What happens to out of band energy?
- Quick look to spectrum generated by the beam: slides from “Bunch length monitoring using a spectrum analyzer”, J. Banuelos et al., DEELS23

Generated spectrum

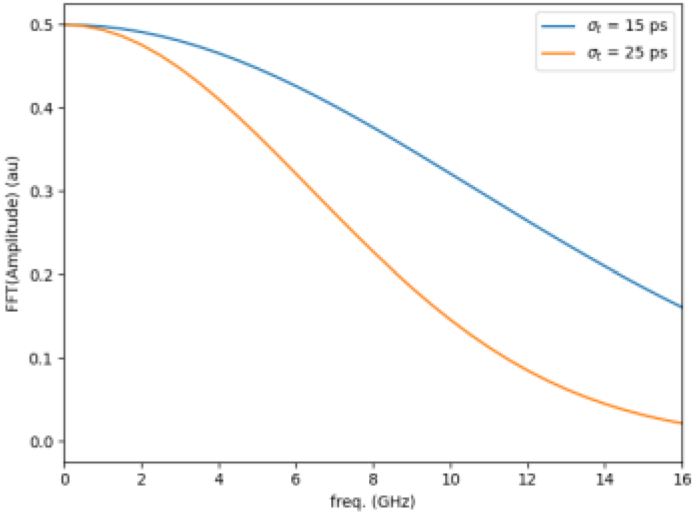
- Assuming that a bunch follows a Gaussian profile described by:

$$s(t) = \frac{A(I)}{\sigma_t\sqrt{2\pi}} e^{-\frac{t^2}{2\sigma_t^2}}$$



- Performing the Fourier Transform:

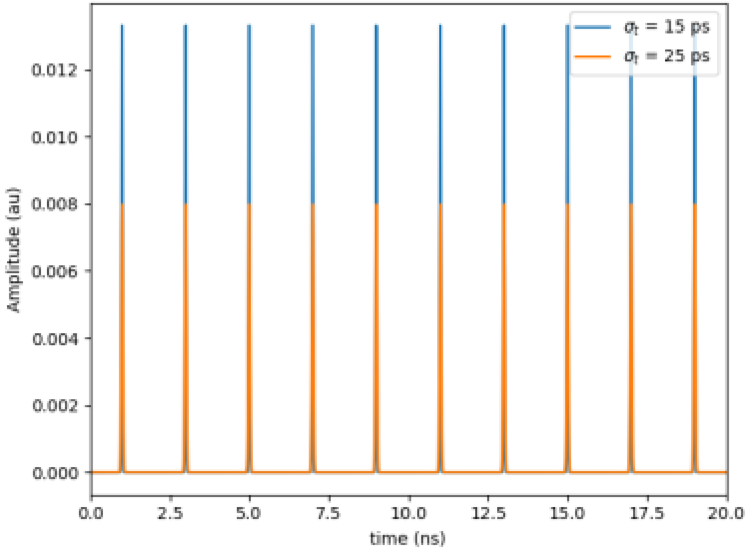
$$s(\omega) = A(I)' e^{-\frac{\omega^2\sigma_t^2}{2}}$$



Generated spectrum

- For the case of a circular accelerator with "h" bunches, spaced by a time "T":

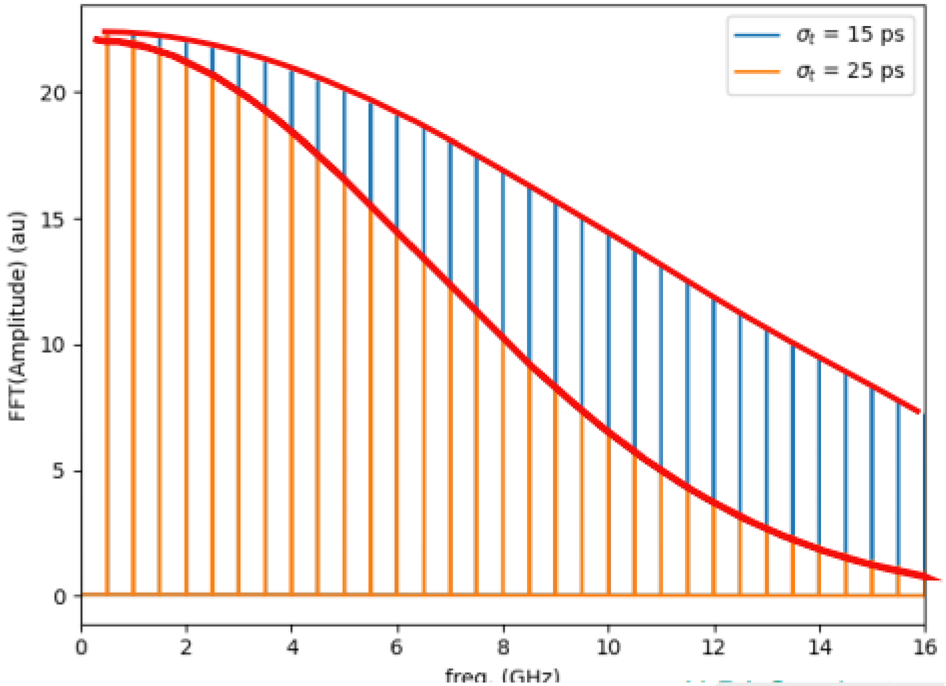
$$s(t) = A(I)' \sum_{n=1}^{h} e^{-\frac{(t-nT)^2}{2\sigma_t^2}}$$



- In frequency domain:

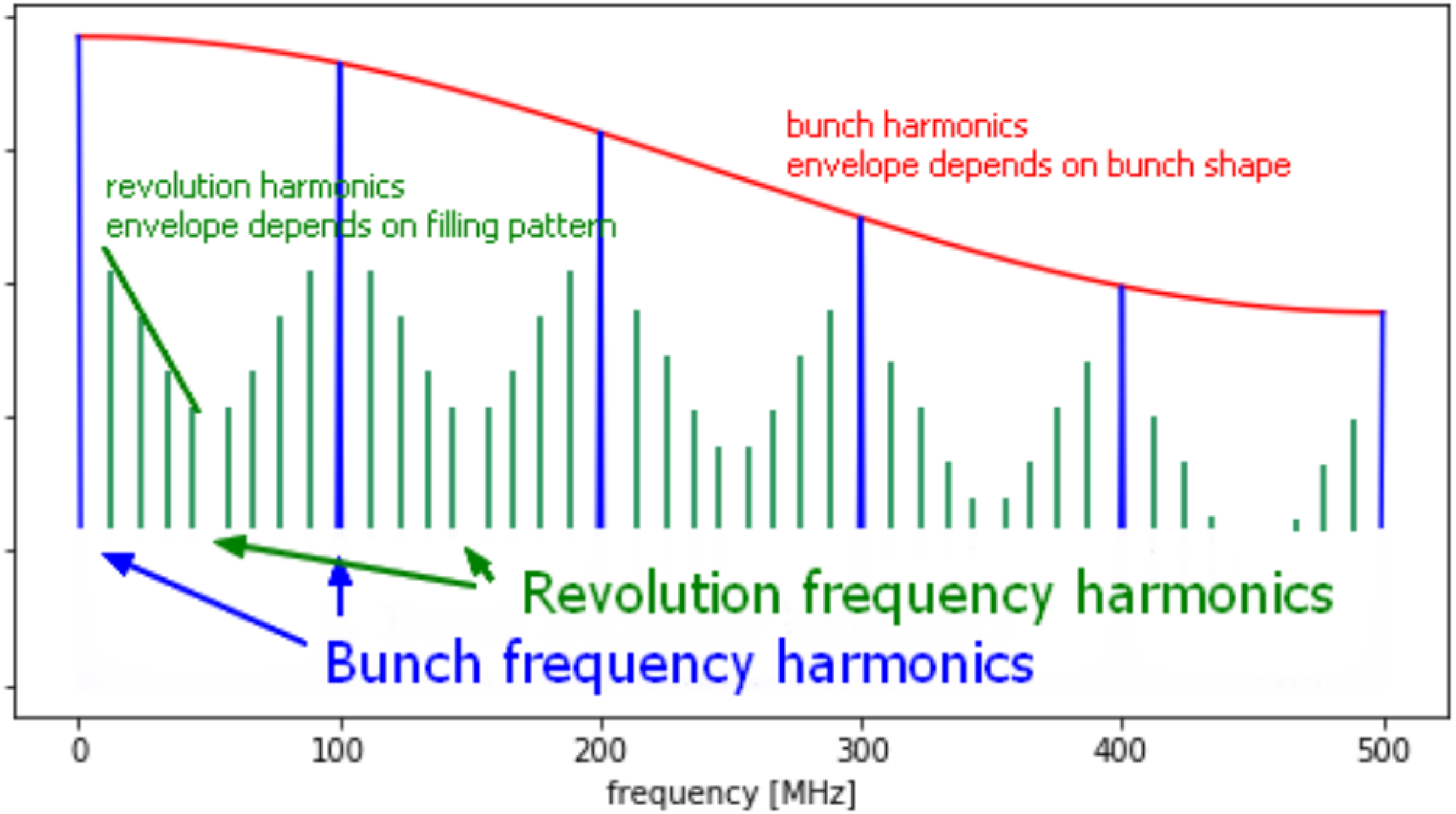
$$s(\omega) = A(I)' e^{-\frac{\omega_0^2 \sigma_t^2}{2}} \sum_{k=1}^{\infty} \omega_0 \delta(\omega - k\,\omega_0)$$

ω_0 is the RF frequency.



Generated spectrum

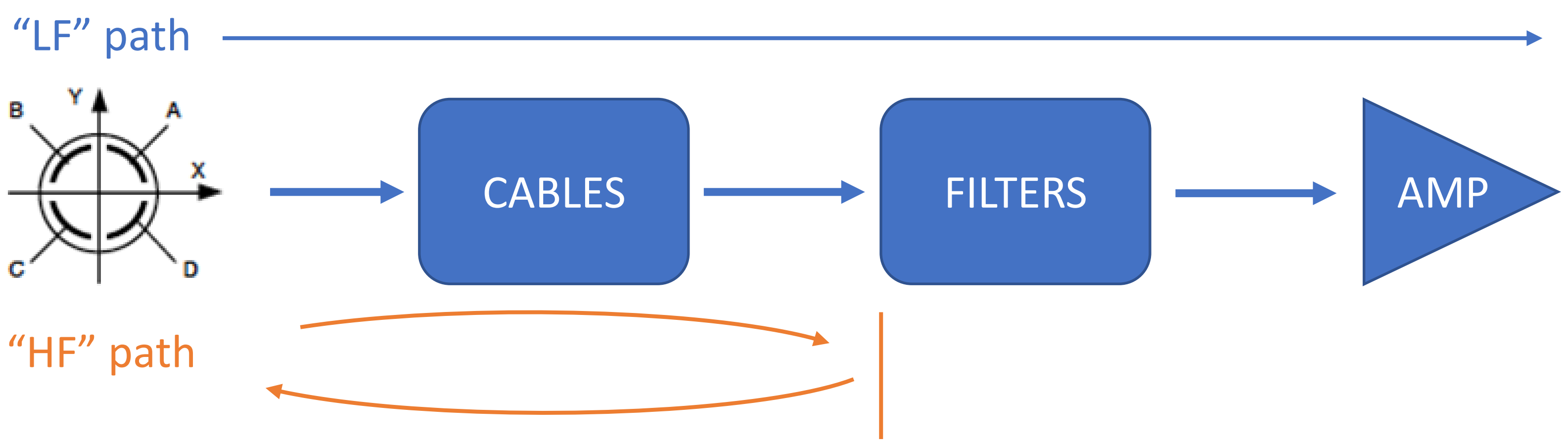
- Theoretical signal in freq. domain*
  - Note: in the f_{RF} harmonics, the amplitude does not depend on the filling pattern!



*H. Schmickler, Proceedings of the CERN–Accelerator–School course: Introduction to Particle Accelerators pp. 535

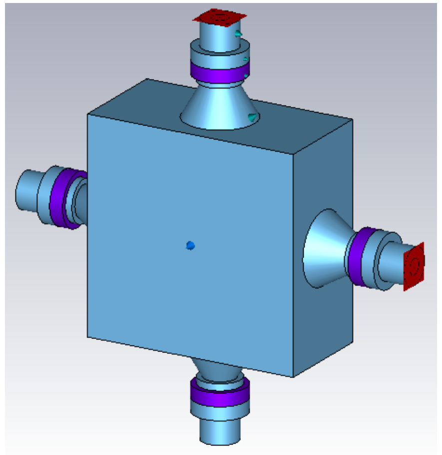
Topics

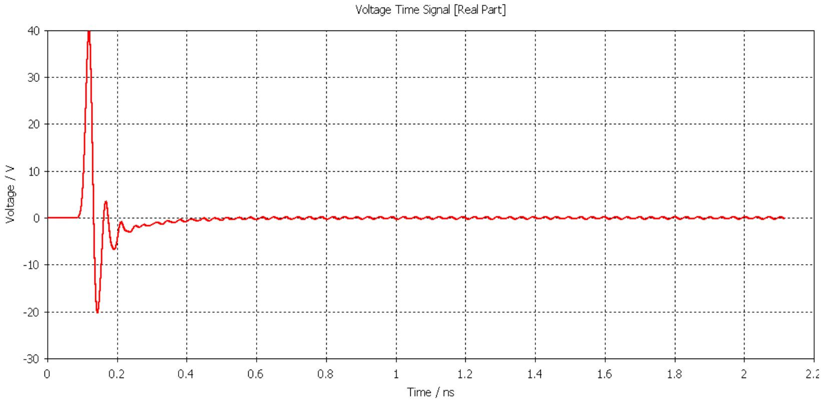
- Upper frequency limit (cutoff) depends on bunch length
- Pick-ups typically have a high pass characteristic
- The reflected energy lies in the upper part of the spectrum and is going back to the pickup
- Putting analog front ends nearer to the pickups can reduce the (beneficial?) attenuation of cables

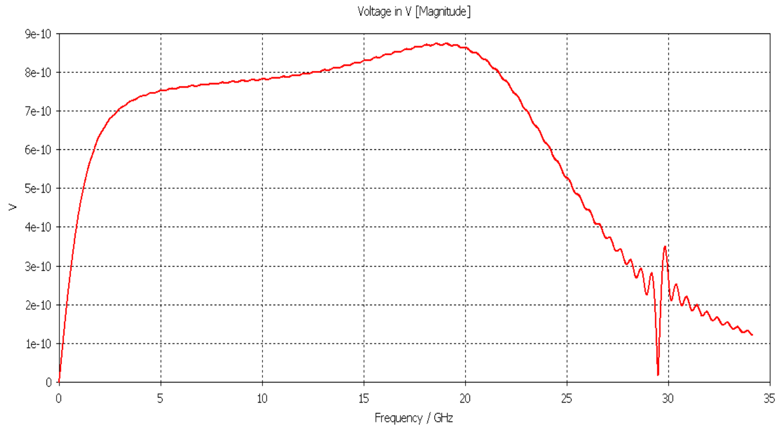


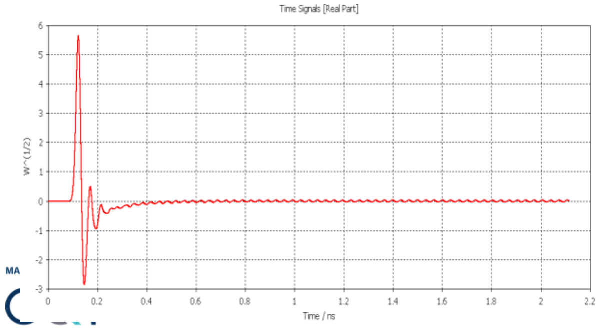
Electromagnetic simulations

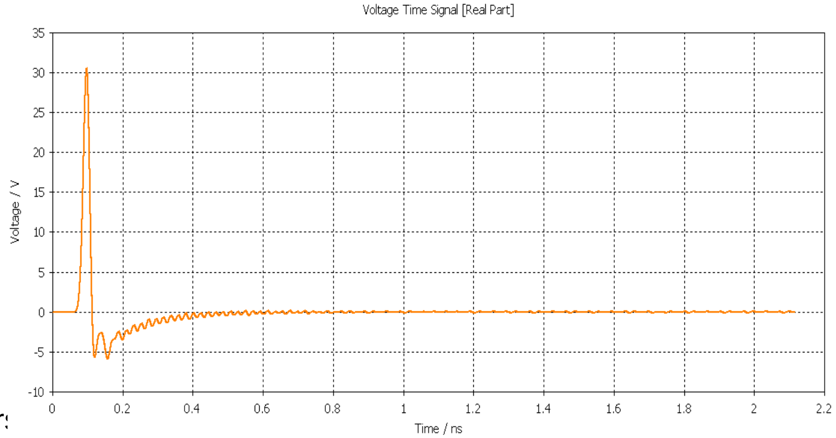
- Beam Coupling Impedance and Transfer Impedance are affected by pick-ups termination conditions
- Nominal operation: RF ports are 50 Ohm terminated (short run)

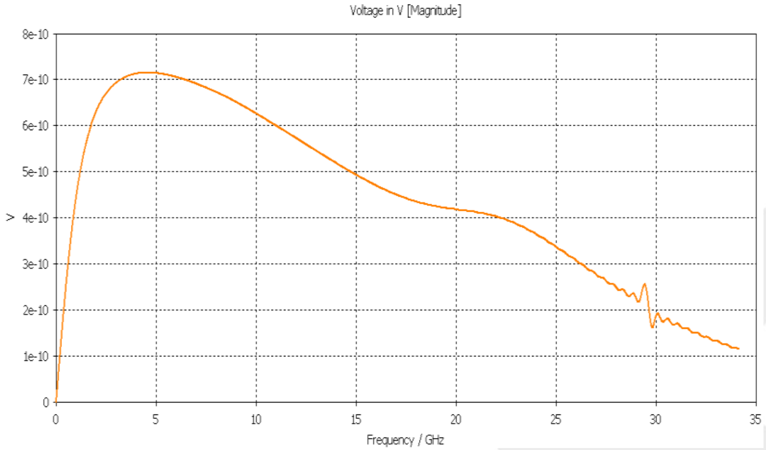








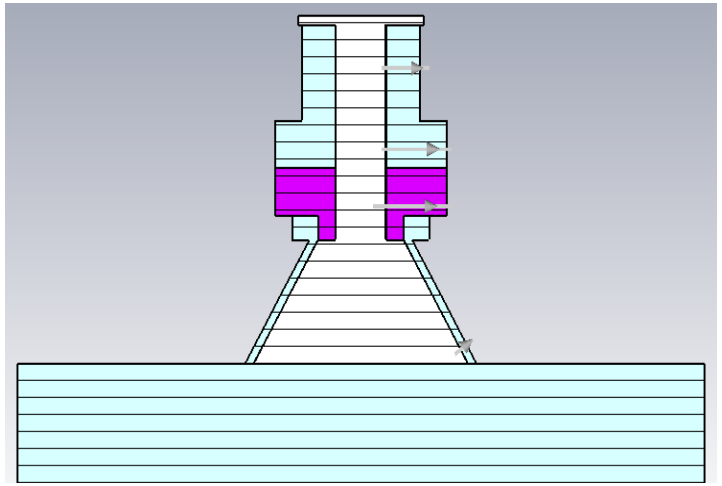


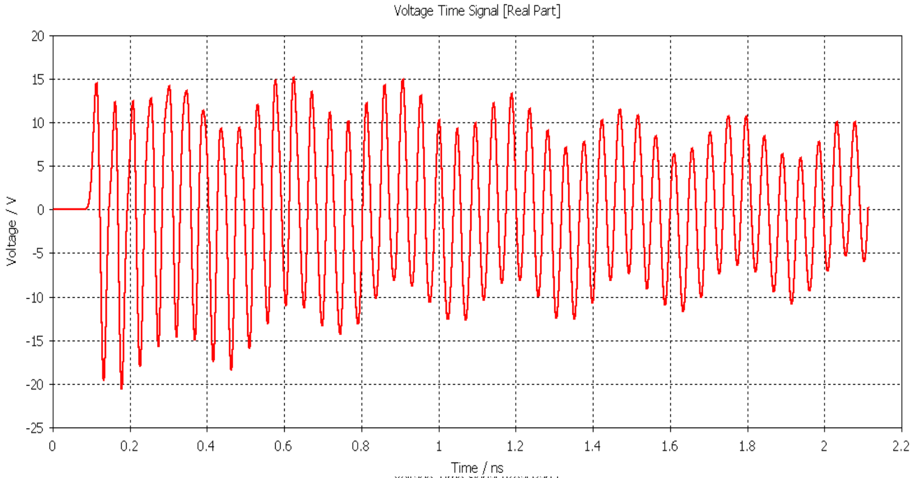


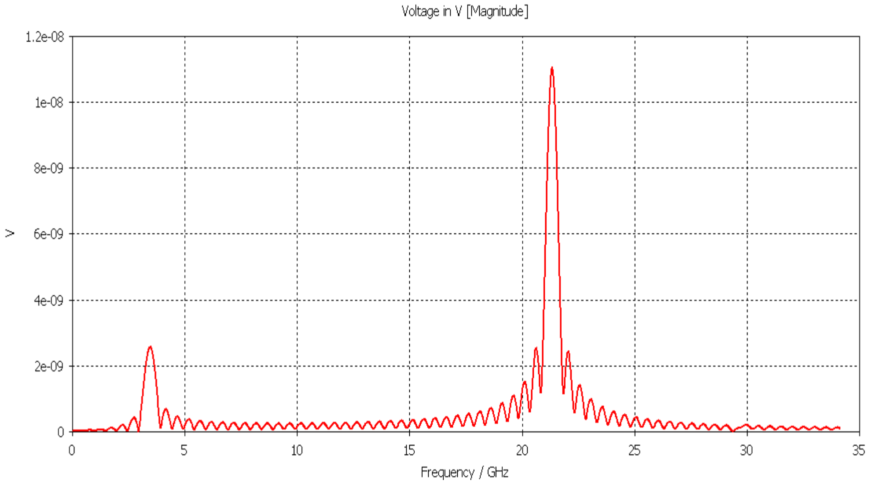
Reflective vs Reflectionless RF Filters

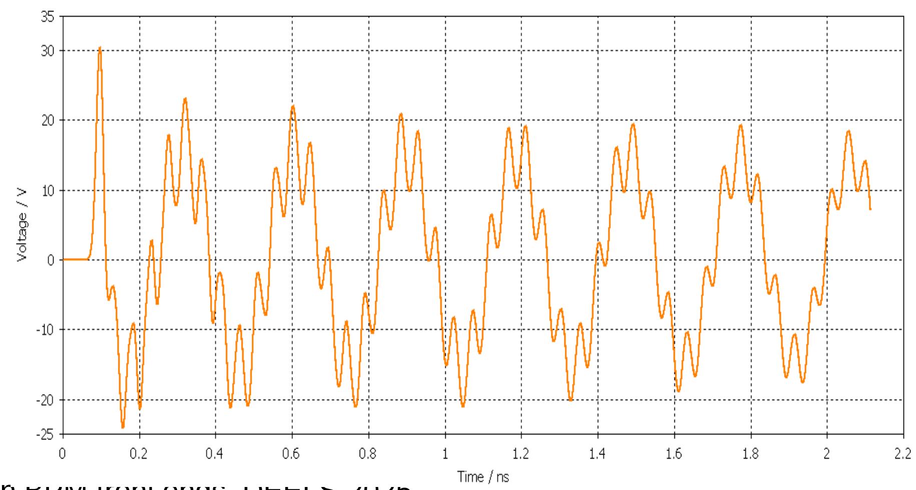
Electromagnetic simulations

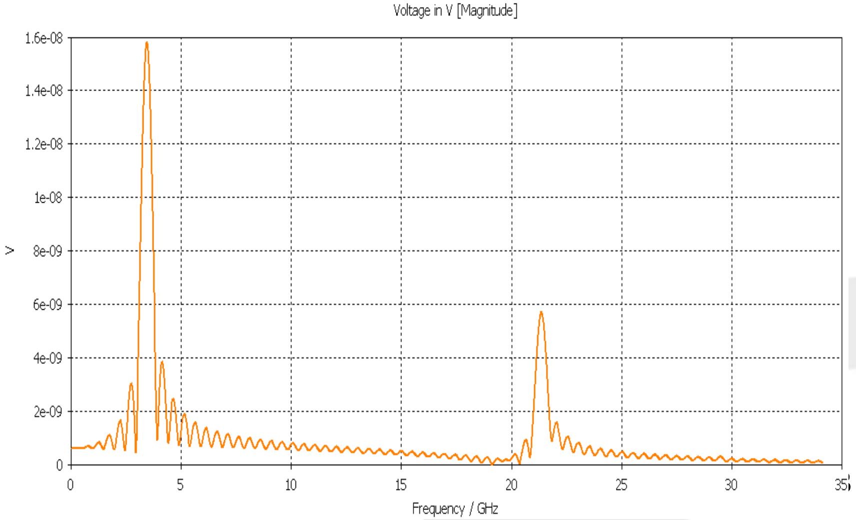
- RF ports are short circuited by conducting disks (short run)





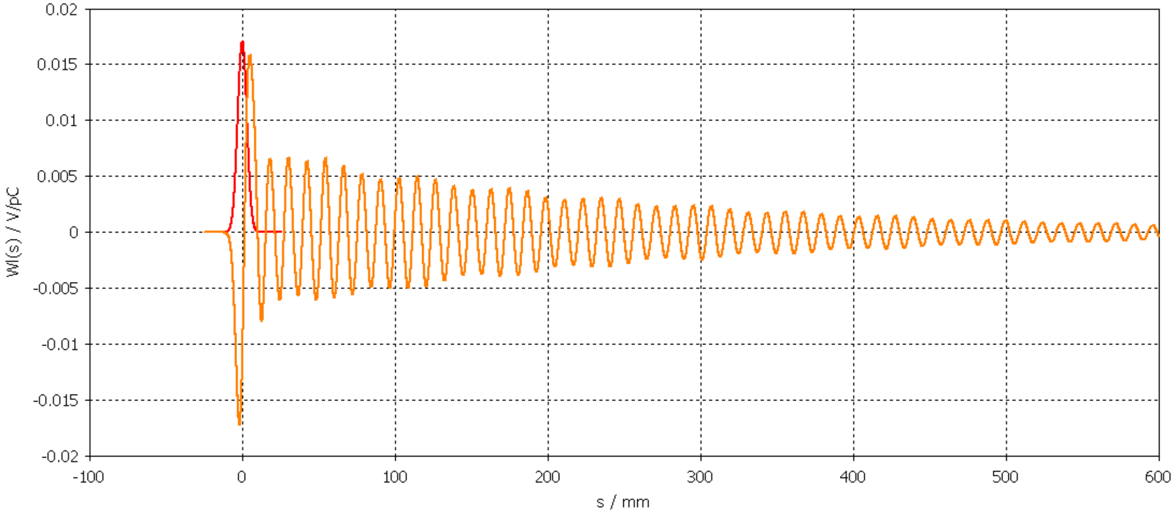


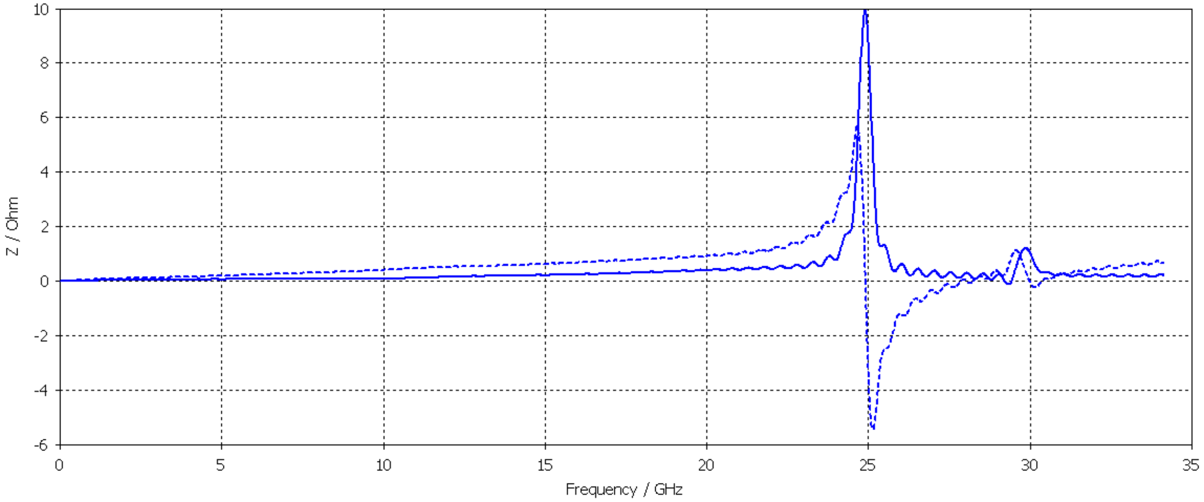


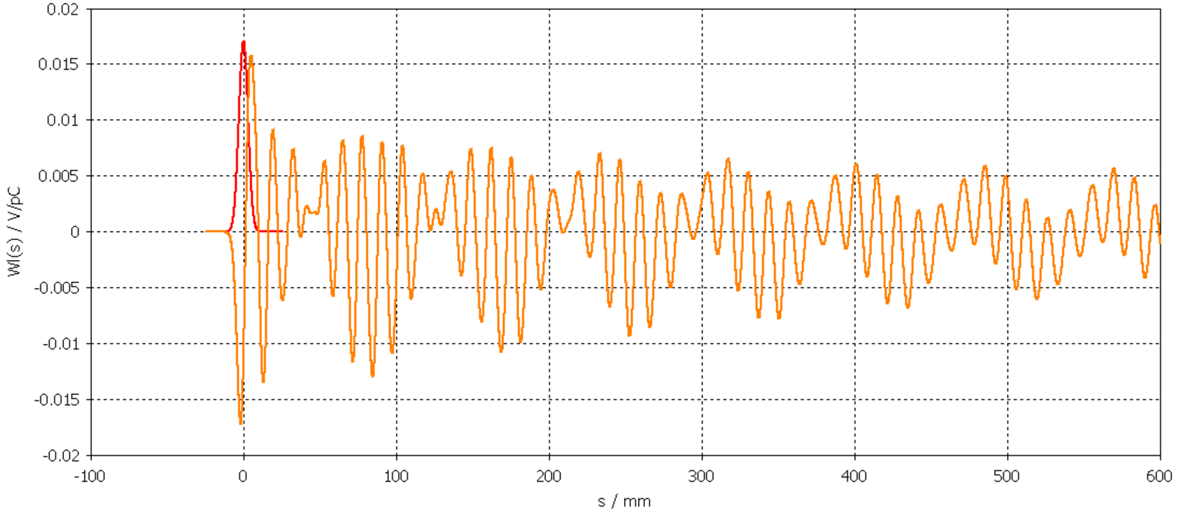


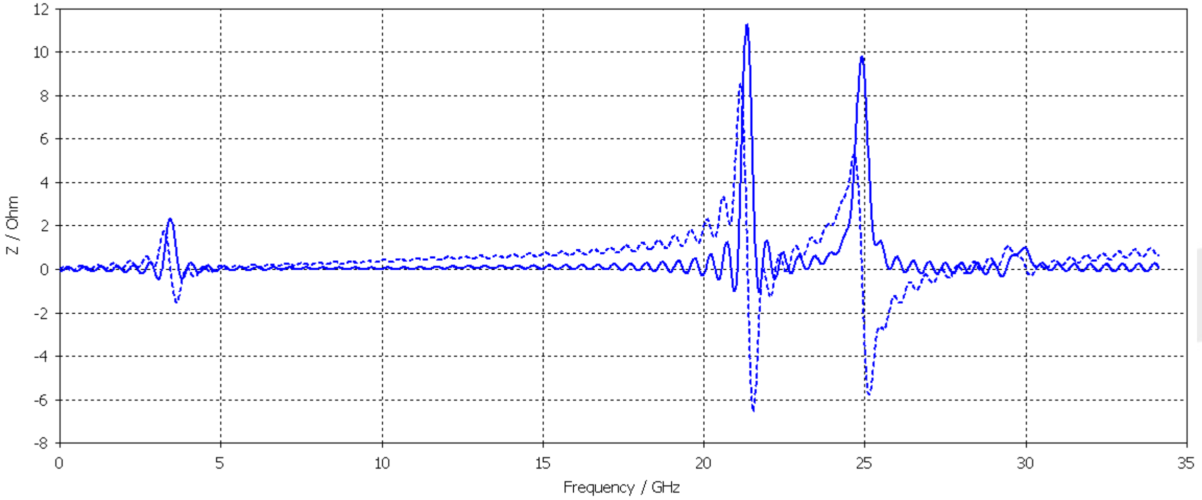
Electromagnetic simulations

- Comparison between wake potential and coupling









Questions

- Can we quantify the energy extracted and the reflected respectively by the pickup and the filter?
- What could be the effect of the reflected energy?
  - Pickup heating?
  - Contamination of signal seen by BPMs electronics?
- Is this something we need to be concerned about?

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Thank you!

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