CERN

Slow Extraction workshop 2017

Magnet power supplies and Slow extraction

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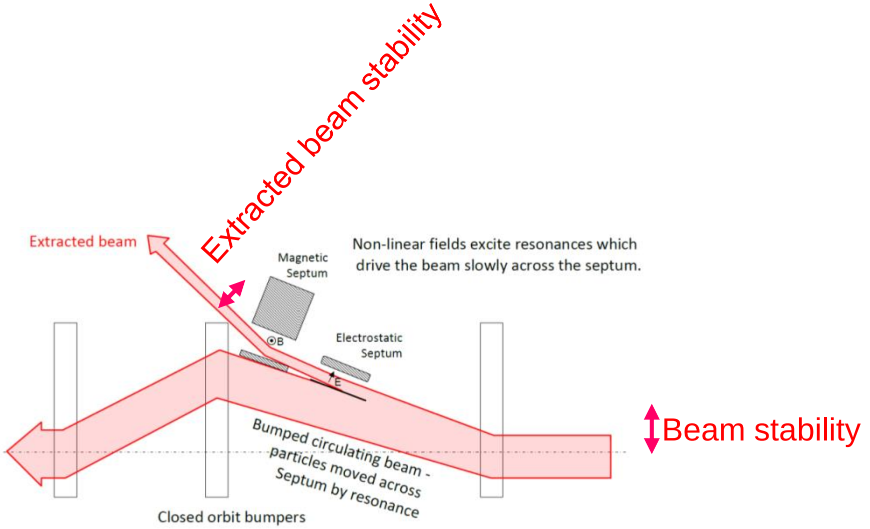
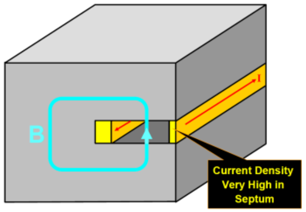
- Example of problem
- Magnetic field ripple
- The harmonics generated by power supplies
- Power supply technologies
- Power supply control
- Example of improvement
- Summary

Slow extraction

The slow extraction process is strongly dependent on the stability of the septum magnetic field but also of the circulating beam stability.

Septum magnet



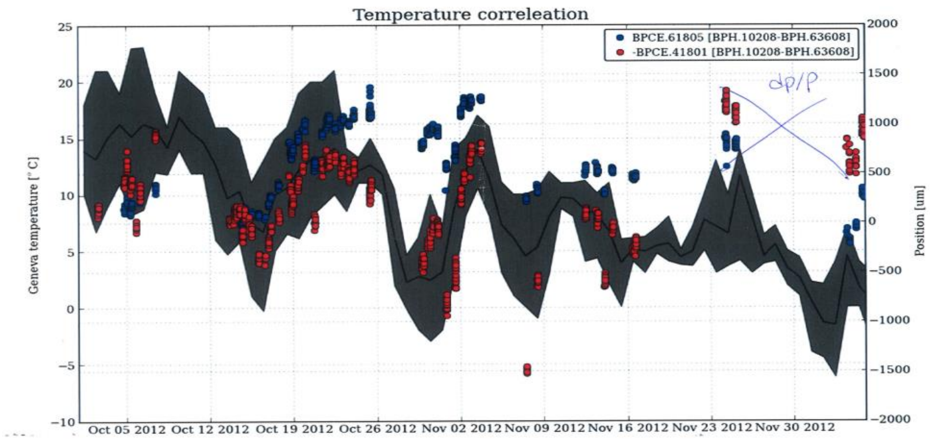


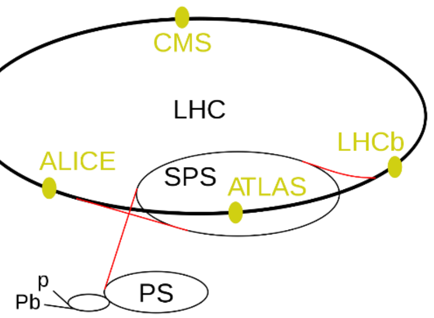
Slow extraction clients are the most sensible clients to the magnet power supply stability and reproducibility!

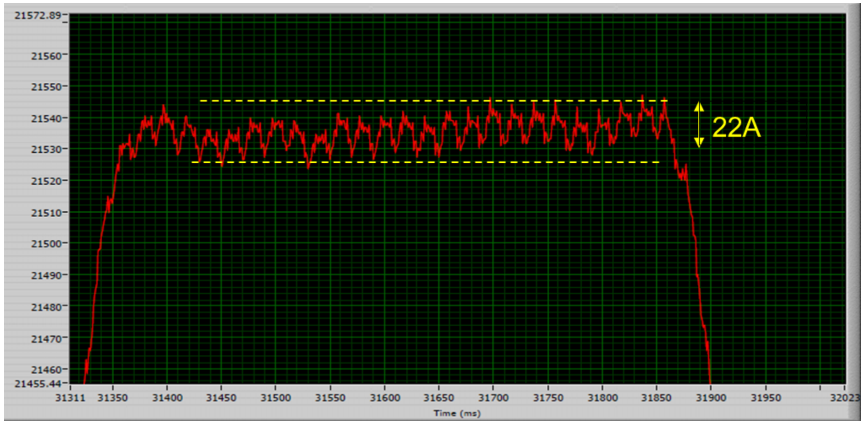
Example of problem

Example of septum magnet field stability for LHC transfer line TI2 TI8 (even for a fast extraction process)

The beam was difficult to inject in the LHC due the current ripple of the SPS extraction septum.

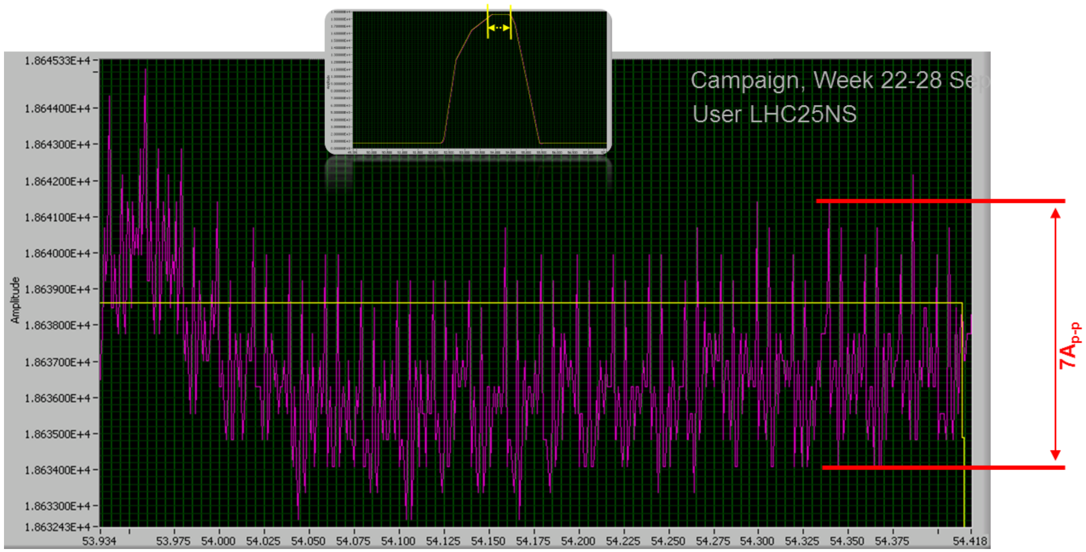






Example of problem

The problem was solved by reducing the current ripple from 22App to 7App.

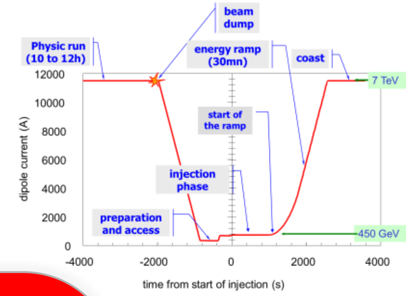


The problem was solved by increasing the size of the output filter of the septum power supply.

So, Yes it is possible to get high beam stability!

Magnet power supply

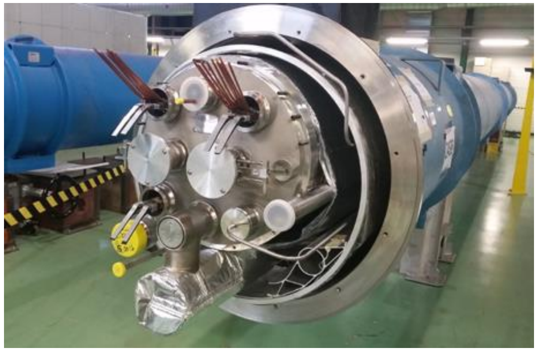
The tasks of a power supply are to process and control the flow of electric energy by supplying voltage and current in a form that is optimally suited for user loads.



Energy source

Control from CCC

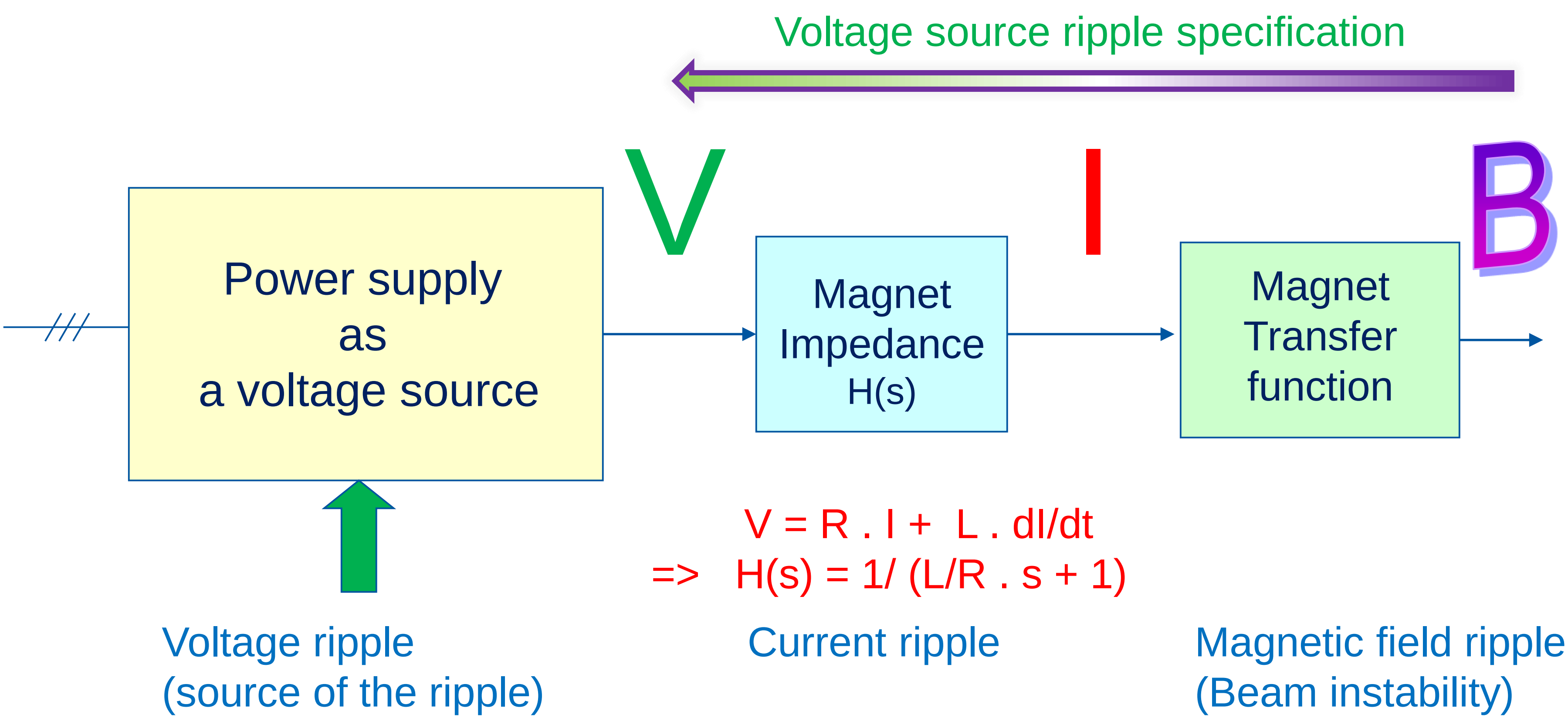
Application



Magnetic field ripple

The voltage source is at the origin of the ripple.

Its stability is defined from the magnetic field stability, through the circuit parameters.



Magnetic field ripple

$$B(f) = T_{\text{Vacuum}}(f) \times T_{\text{ItoB}}(f) \times I(f)$$

$$B(f) = T_{\text{Vacuum}}(f) \times T_{\text{ItoB}}(f) \times T_{\text{VtoI,load}}(f) \times V(f)$$

$I(f)$ current ripple (Circuit specifications)

$V(f)$ voltage ripple (Power converter specifications)

$T_{\text{VtoI,load}}(f)$ transfer function of the load (circuit) seen by the power converter

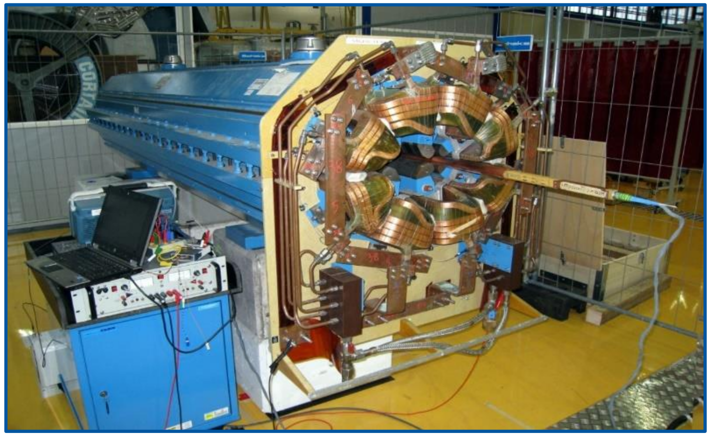
$$I(f) = \frac{V(f)}{|R_{circuit} + 2\pi i \cdot L_{circuit}(f) \cdot f|}$$

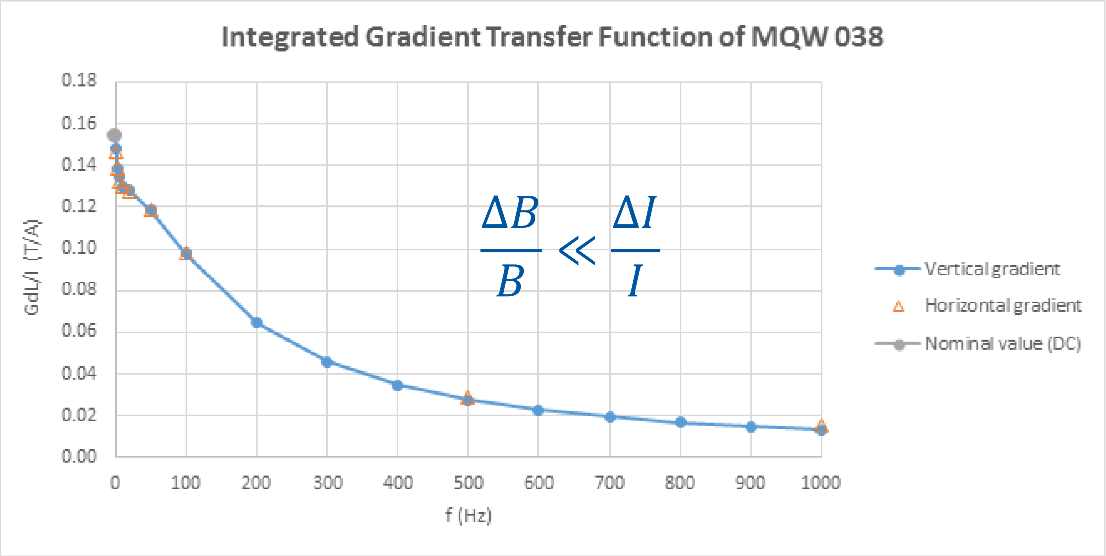
$T_{\text{ItoB}}(f)$ transfer function from the input current of the magnet to the magnetic field

$T_{\text{Vacuum}}(f)$ transfer function of the cold bore, absorber, beam screen etc., $T_{Vacuum} \leq 1$

Impact of vacuum chamber

The vacuum chamber helps to reduce ripple but at high frequency (above 100Hz).





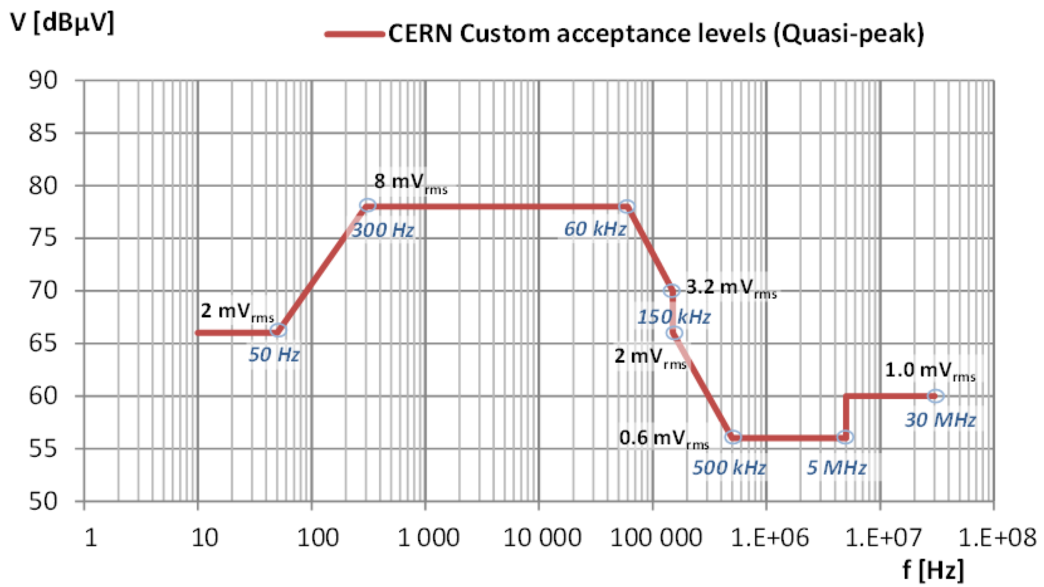
Courtesy TE-MSC-MM Buzio et al. 2014

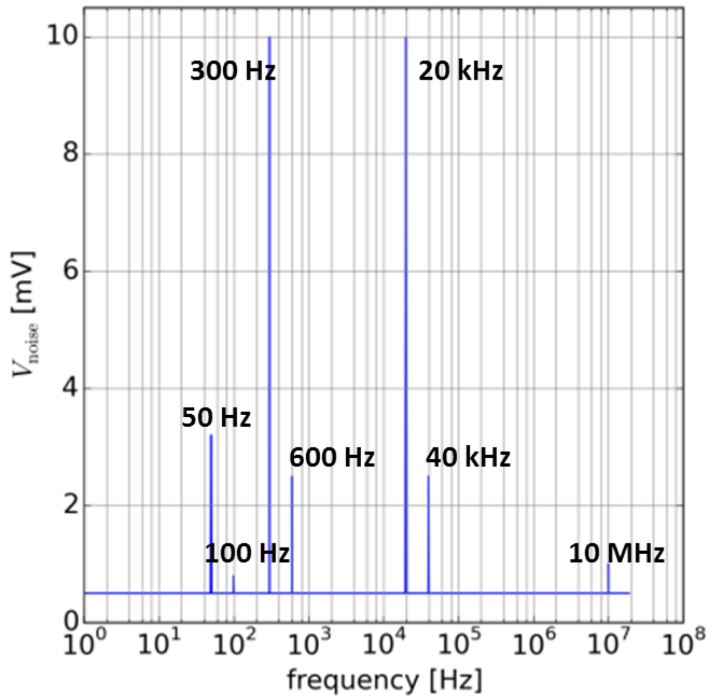
Voltage source ripple

The voltage ripple has to be specified for all frequencies.

<50Hz:	for regulation performance
50-1200Hz:	for grid disturbance
1-150kHz:	for power supply switching frequency
>150kHz:	for EMC

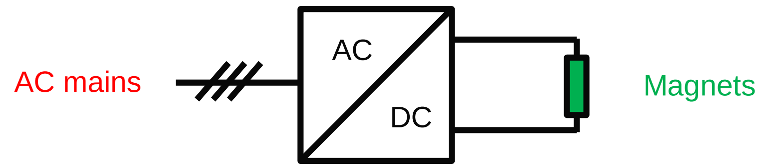
A standard was defined for LHC power supplies





Thyristor rectifiers

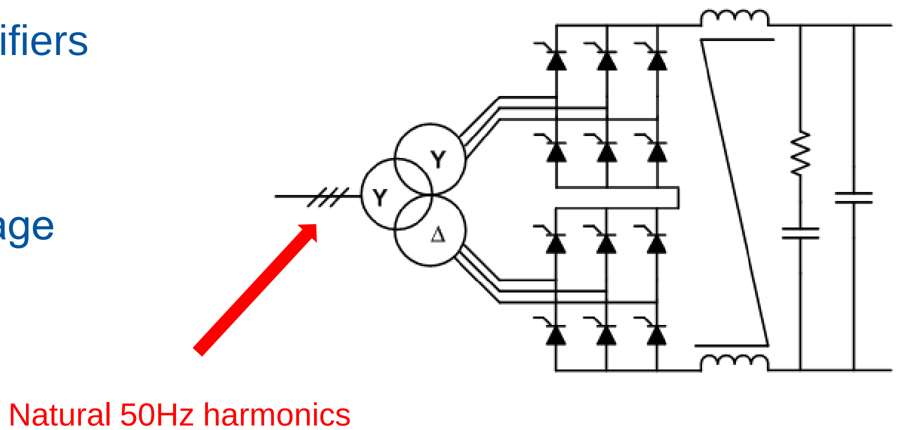
Thyristor rectifier



Only one stage of conversion from the grid

Strong 50Hz harmonics

SPS machine is full of thyristor rectifiers



Best design : ΔV = 1‰ of Max voltage

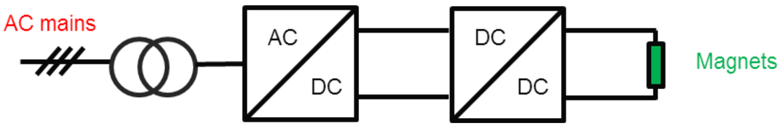
Example: Vout = 1000V

ΔV = 1V at 600Hz

To do better => need an active filter to kill the voltage ripple.

IGBT converters

IGBT converters

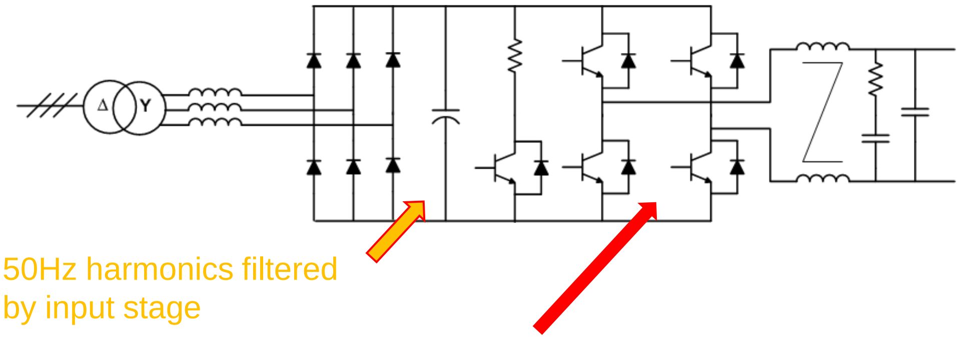


Double stage of conversion from the grid

No 50Hz harmonics, little 300Hz

2.5kHz to 10kHz harmonics (IGBT switching frequency)

PS machine is full of IGBT converters

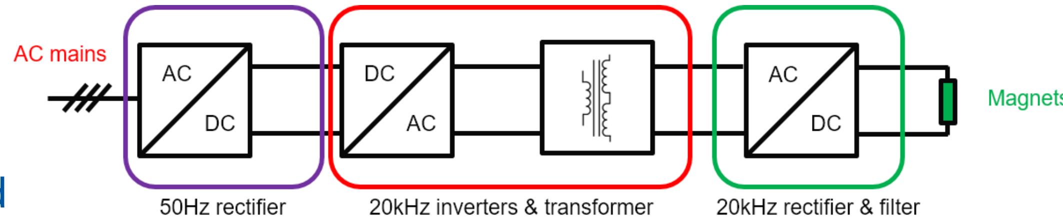


50Hz harmonics filtered by input stage

Few kHz harmonics

Switch-mode power supplies

Multi-stages converter with high-frequency inverters

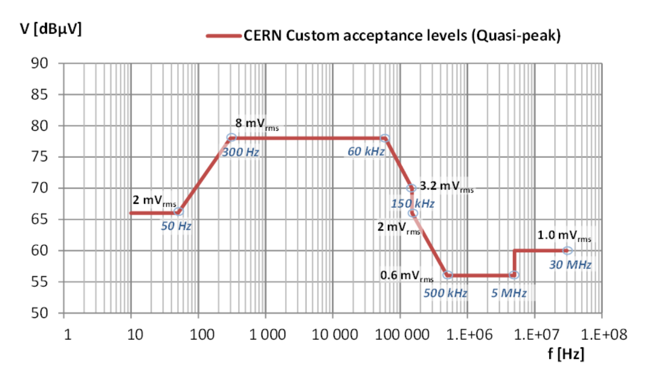


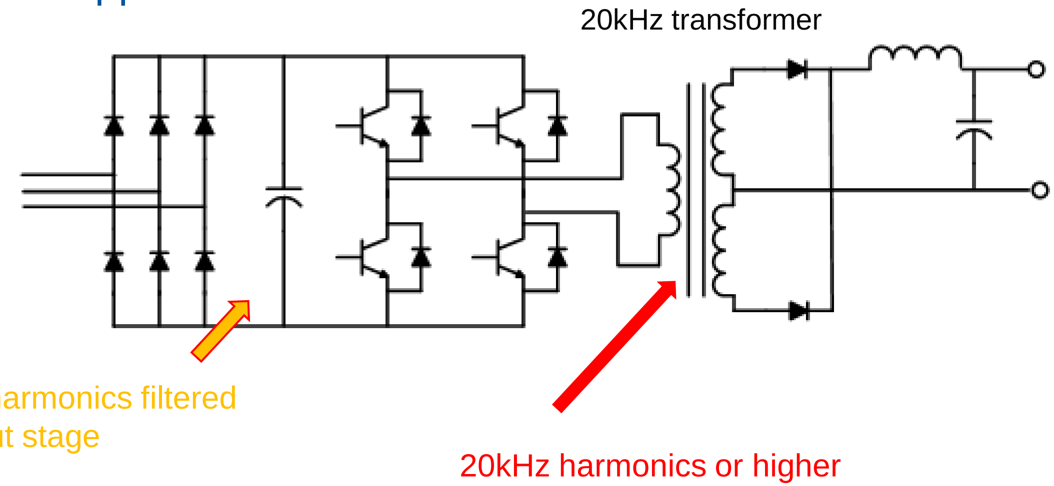
Multi-stages of conversion from the grid

No 50Hz harmonics, little 300Hz

20kHz harmonics (inverter switching frequency)

LHC machine is full of switch-mode power supplies.

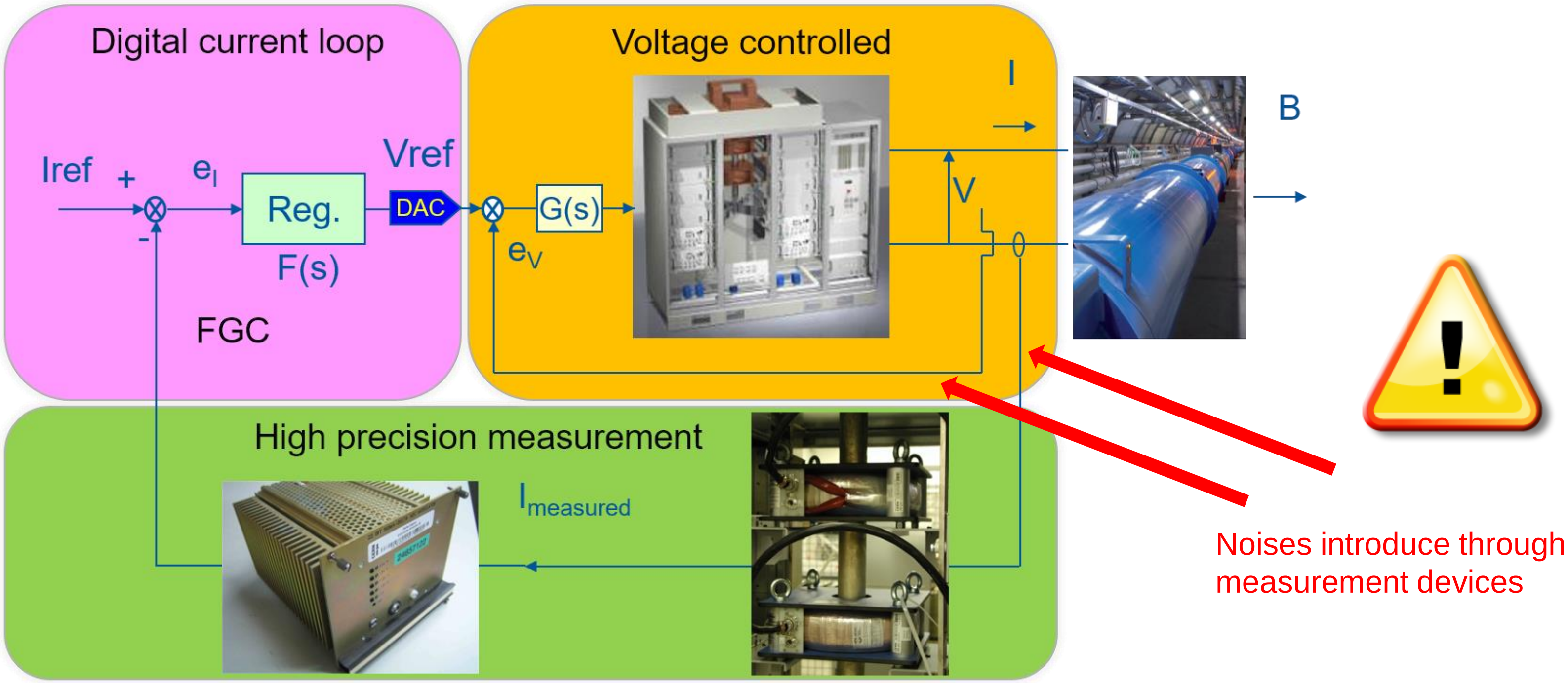




Noises introduced in control

Even if the power part is very well done, the 50Hz harmonics can be introduced by the control system through the current and voltage measurements.

Control electronics is a key element to get a high stability.



Noises introduce through measurement devices

Example of improvement

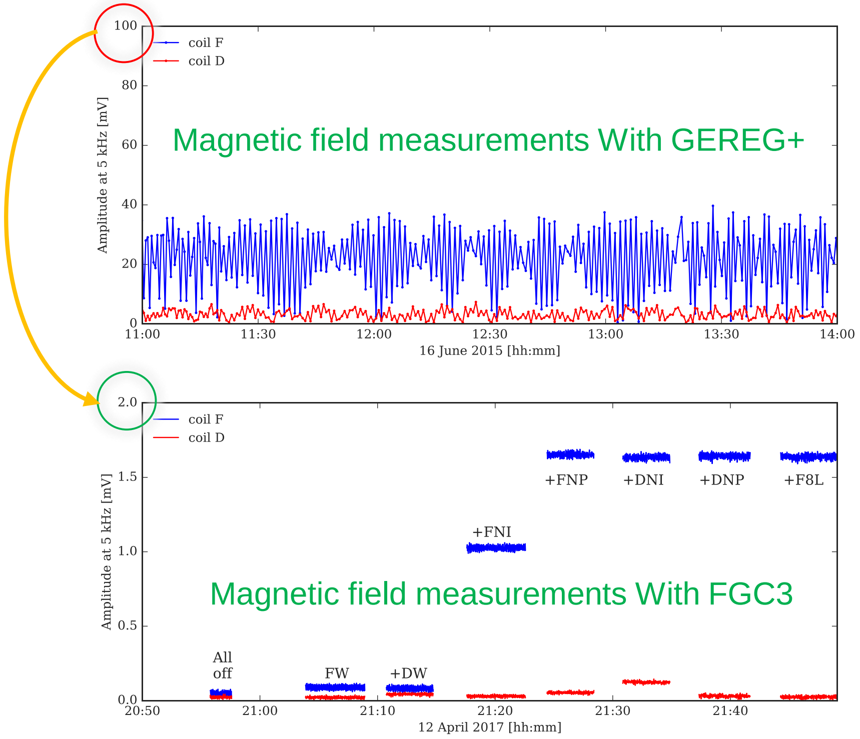
Example of Pole Face Windings (PFW) of the PS, where the 5kHz switching frequency was disturbing the MTE (multi-turn extraction). The EAST area slow extraction was fine in the same conditions.

The stability of the tune was affected by the 5kHz ripple.

The PFW control electronics was upgraded for a full digital electronics (FGC3, CERN standard).

All PFW converters are synchronised with central timing system up to the IGBT firing.

The MTE reproducibility problem was solved by this upgrade.

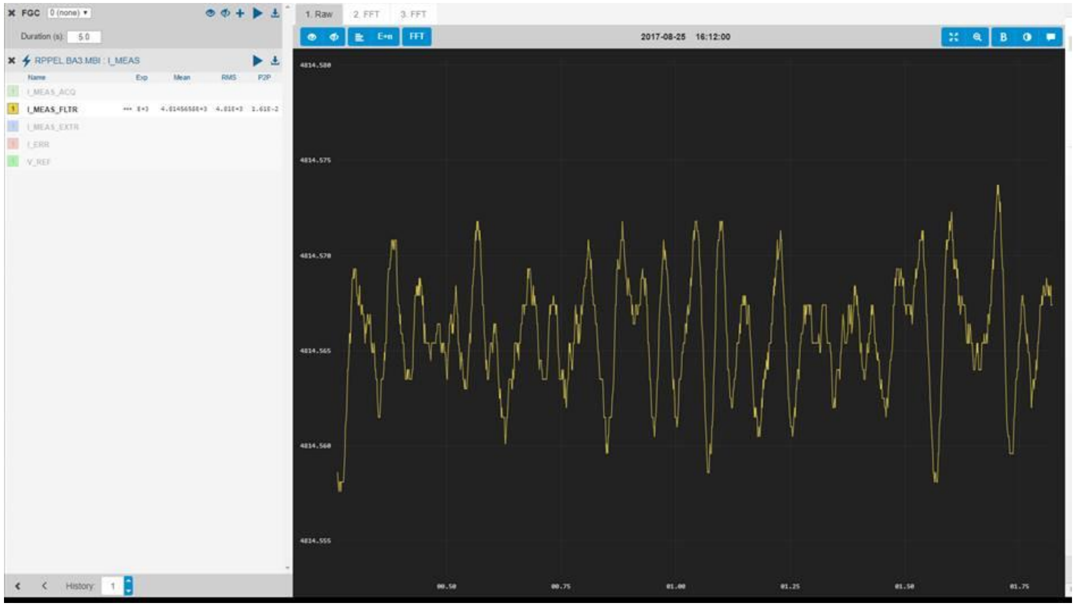


Present SPS issue

Recent change in the SPS slow extraction process put a new performance request on the QF power supply and dipole power supply.

This power converters are thyristor rectifiers with active filters.
The current ripple, generating the harmonics in the slow extraction, has a level of 10ppm (20mA over 2kA). Quite a good performance for this very old technology (power and control from the seventies)!

Improvements are under study mainly on the control electronics.



Summary

Magnet power supplies are key devices for slow extraction performance.

The voltage source is at the origin of current ripple but the amplitude depends of the magnet impedance.

Thyristor rectifiers generate strong 50Hz harmonics.

Switch-mode power supplies shouldn't generate 50Hz harmonics.

High-performance control electronics is mandatory to get high current stability.

Low-harmonics (<50Hz) are coming form the control electronics (current regulation).

50Hz harmonics can be introduced as parasitic noise through the measurement devices and the voltage source will generate 50Hz harmonics.

Yes, it is possible to make high stabilized power supplies.

WANTED

Which power supply is making this bad spill?