Rotating Coil Session Summary

Zack Wolf

General Remarks

In principal, rotating coil measurements are straightforward.

In practice, to make accurate measurements, much ingenuity and hard work is required.

This session was a display of ingenuity and hard work!

General Topics

- Coil calibration
- Coil construction techniques
- Techniques for faster meassurements
- Integrator improvements
- Field reconstruction when the magnet geometry does not match a coil geometry.
- Alternate techniques when a coil is not available

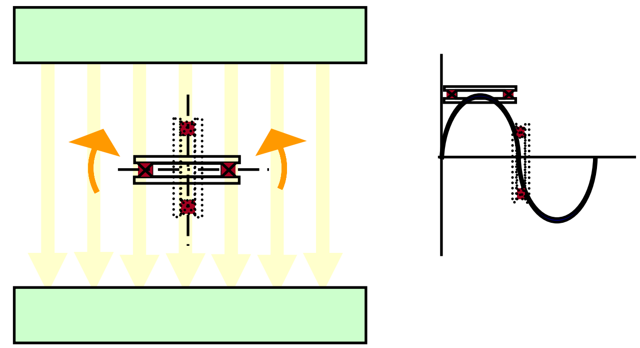
Coil Calibration at CERN, Olaf Dunkel

Dipole Magnet:
• coil area
• relative alignment of main and bucking coils
• coil direction relative to encoder and/or gravity

Quadrupole Magnet:
• coil radius wrt rotation axis

Method of Calibration in Reference Dipole:

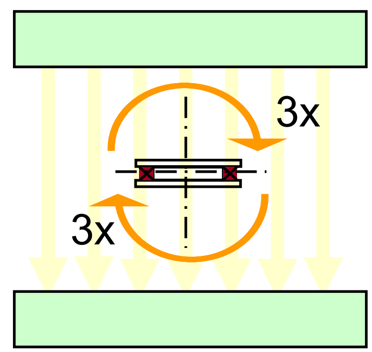
1. App. adjustment to max. (or 0) integrator signal



2. Start integrator → rotation 180° → stop integrator

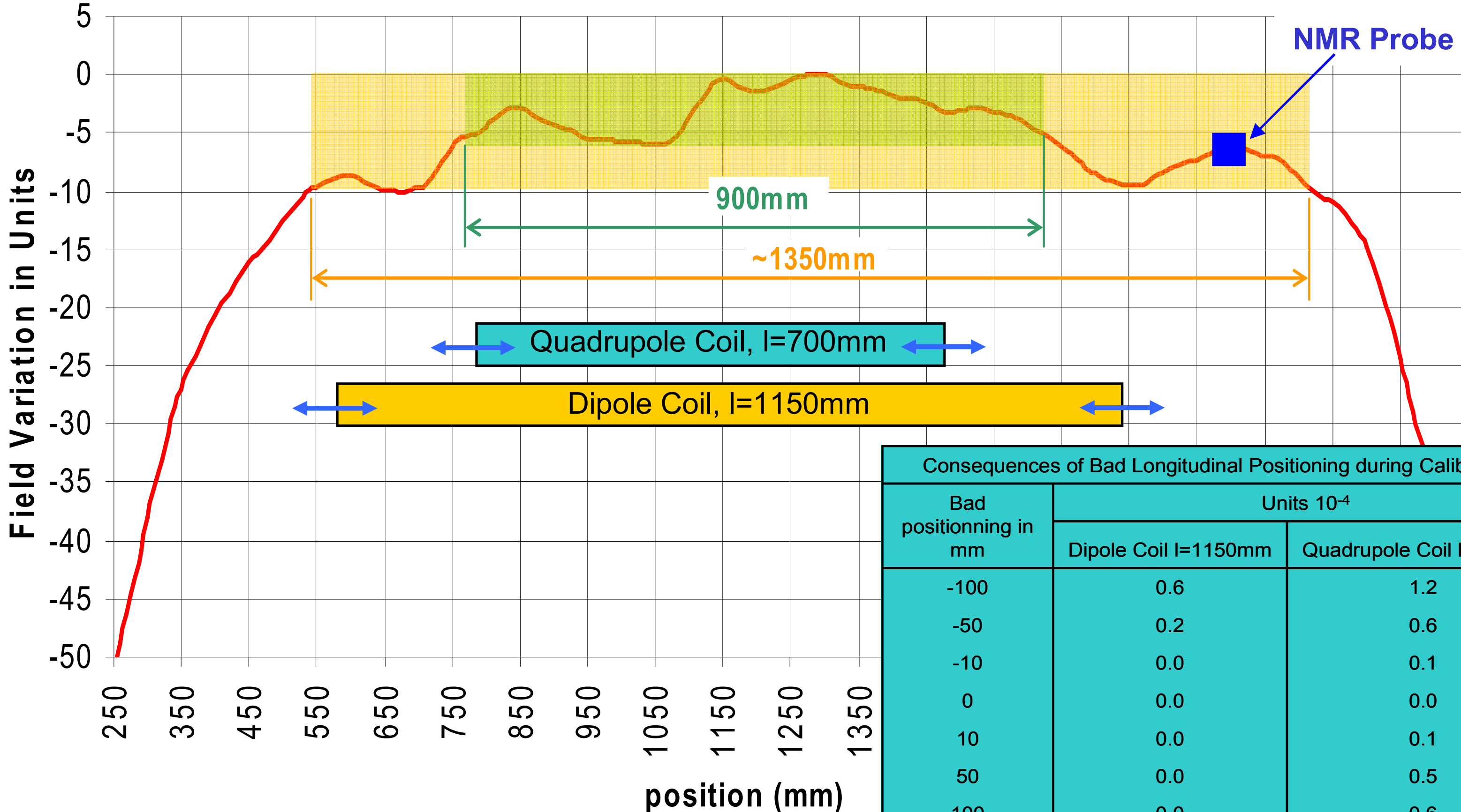
- Repeat 6 times
- Observation of RMS
- Average integrator signal
- NMR-monitored field
- Field correction factor

Coil Area



Reference Dipole:

- Field homogenous within 6 units over ~900mm, within 10 units over ~1300mm
- Importance of longitudinal coil positioning for good reproducibility (in particular for shorter coils)

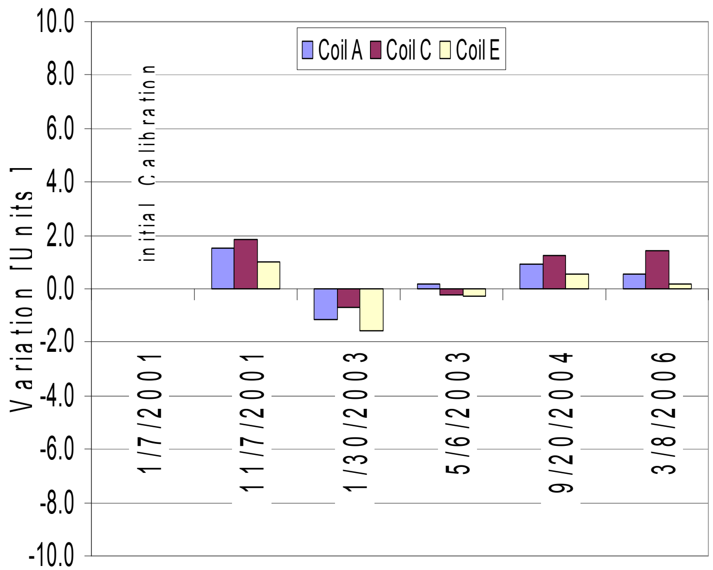


Consequences of Bad Longitudinal Positioning during Calibration		
Bad positionning in mm	Units 10^{-4}	
	Dipole Coil l=1150mm	Quadrupole Coil l=700mm
-100	0.6	1.2
-50	0.2	0.6
-10	0.0	0.1
0	0.0	0.0
10	0.0	0.1
50	0.0	0.5
100	0.0	0.6

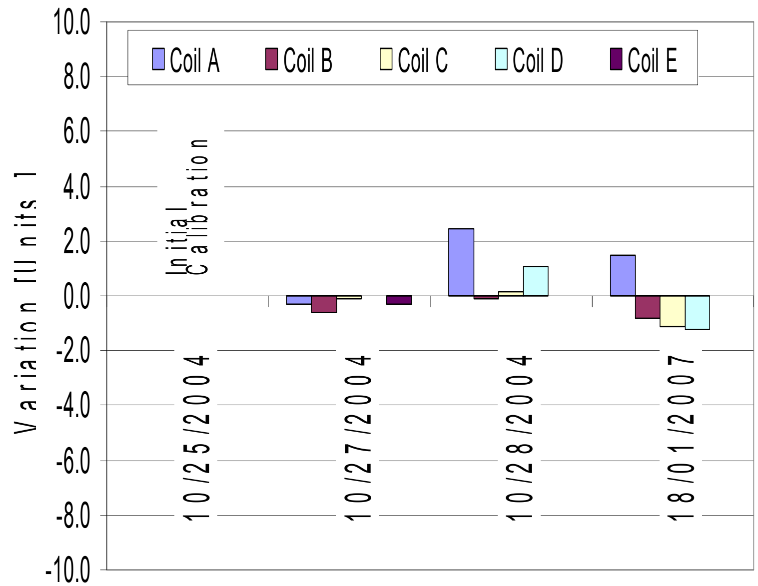
Reference Dipole:

-Good stability of coils (and reference magnet) over years

→ Coil area variation of ~2 units for various calibrations over 5 years



Industrial « DIMM » Mole No. 9
Calibrations 2001-2006



Quadrupole Long Shaft Segment No. 19
Calibrations 2004-2007

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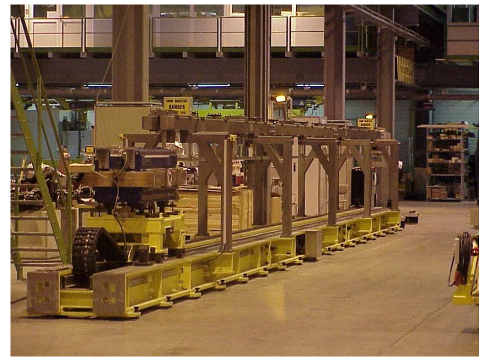
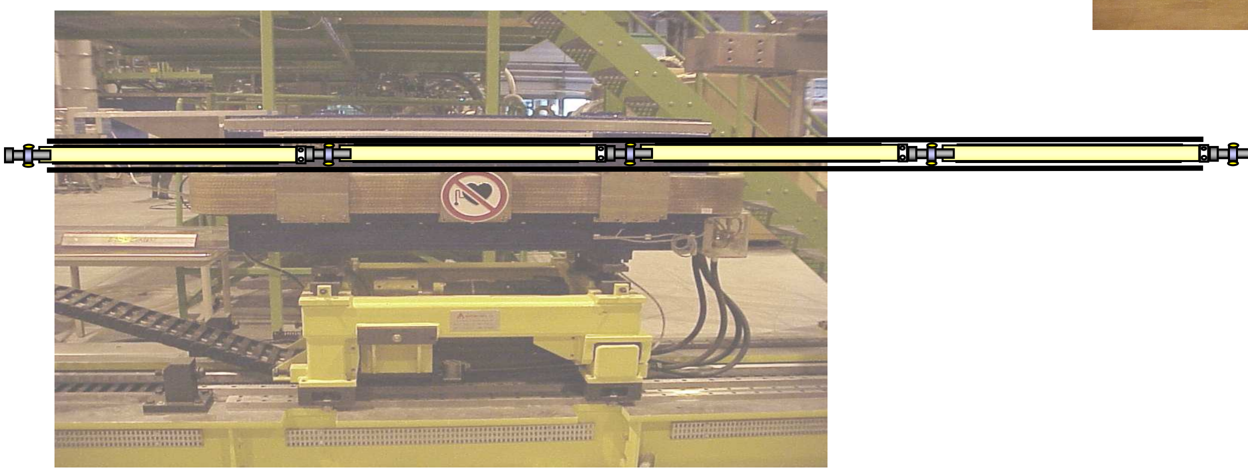
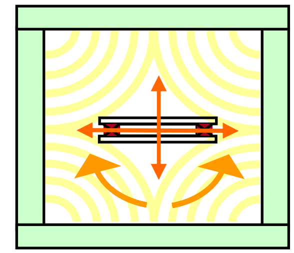
Coil Calibration at CERN, Olaf Dunkel

Dipole Magnet:
- coil area of each coil
- coil angle of each coil

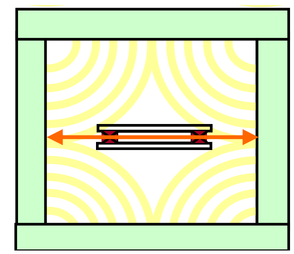




Method of Calibration in Reference Quadrupole:

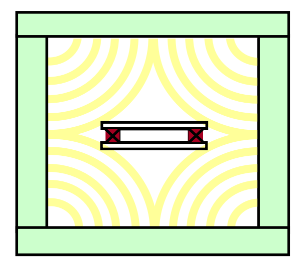


1. Horizontal, vertical and angular adjustment of coil(s) w/r to central field (using integrator signal).



2. Measurement of field gradient by lateral displacement of coil(s) relying on previously calibrated coil sensitivity.
   - Precisely controlled lateral displacement (Heidenhain Sensor, 10^{-3}mm)
   - Gradient measurement with 2 diff. strokes (±10mm and ±15mm)

- Requires Stable Field during the entire procedure !!



3. Measurement of radius by rotation in reading coil sensitivity to B_2
   - Start integrator → rotation 90° → stop integrator
   - 4x counterclockwise, 4x clockwise
   - Observation of RMS
   - Previously measured gradient
   - Average integrator signal
   - Previously calibrated coil area

$\left.\begin{array}{l}\text{- Previously measured gradient}\\\text{- Average integrator signal}\\\text{- Previously calibrated coil area}\end{array}\right\}$ Coil Radius

- No need to know exact gradient (provided it is stable!)
- Method relies entirely on coil sensitivity

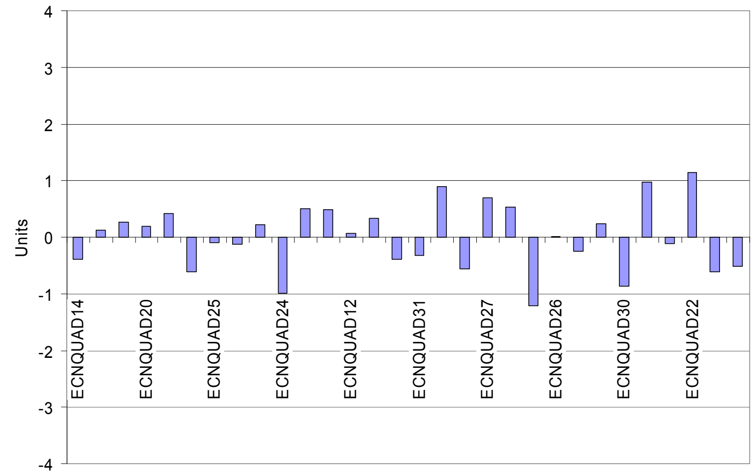
Reference Quadrupole:

Improvements of radius calibration:

Repeatability of radius measuremens:

- 10 different quadrupole long shaft sectors, 3 repetitions each

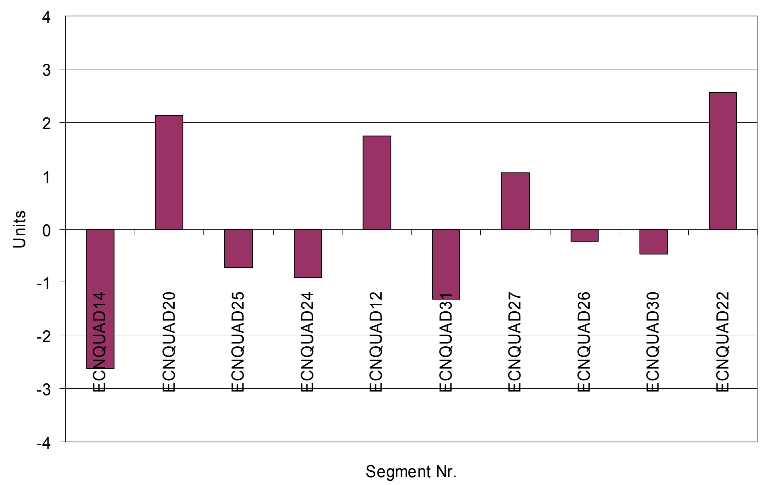
→ Uncertainty: < 2 units (peak to peak)



Reproducibility of radius measurements:

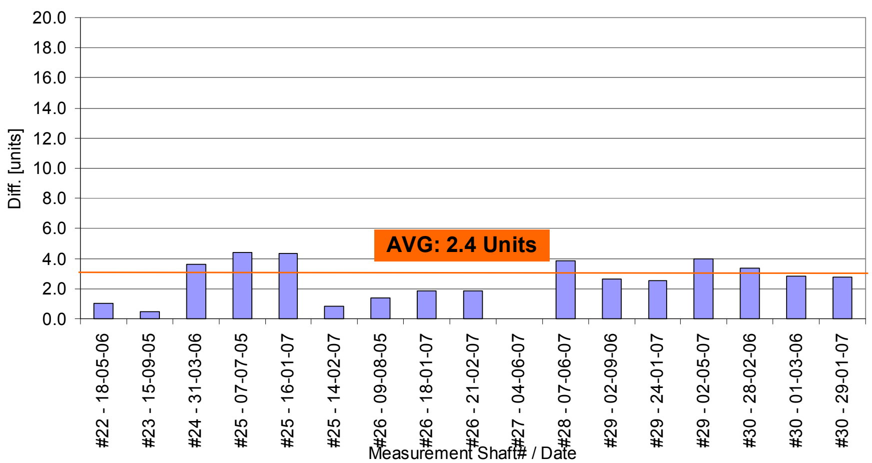
- Variation w/r to average measured on 10 different quadrupole long shaft sectors

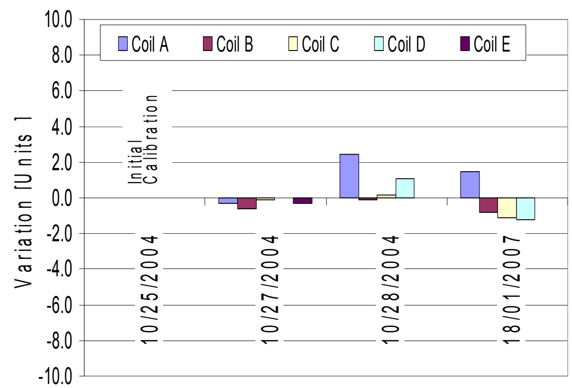
→ Overall uncertainty: < 5 units (peak to peak)



Coil Calibration at CERN, Olaf Dunkel

Results:
- excellent repeatability over years
- good agreement with other methods





Circuit Board Construction, Joe DiMarco

Basic Idea:

Radial coil sensitive to all harmonics

Dipole Bucking Coil sensitive to higher harmonics

Generalized Rotating Probe Harmonics Analysis

Dealing with complex or non-ideal rotating harmonics probes is straightforward

Measure $$\phi(\theta) = \Re \sum_{n=1} C_n K_n e^{(in\theta)}$$

Field $$C_n = B_n + iA_n$$

Any number of wires

Any positions

Wire polarity sign

Probe Sensitivity $$K_n = \sum_{j=1}^{N_{wires}} \frac{L_n R}{n} \left(\frac{(x_j + iy_j)}{R} \right)^n (-1)^{j+1}$$

Complex conjugate of $\phi(\theta)$ FFT

$$C_n = \frac{F_n^*}{K_n}$$

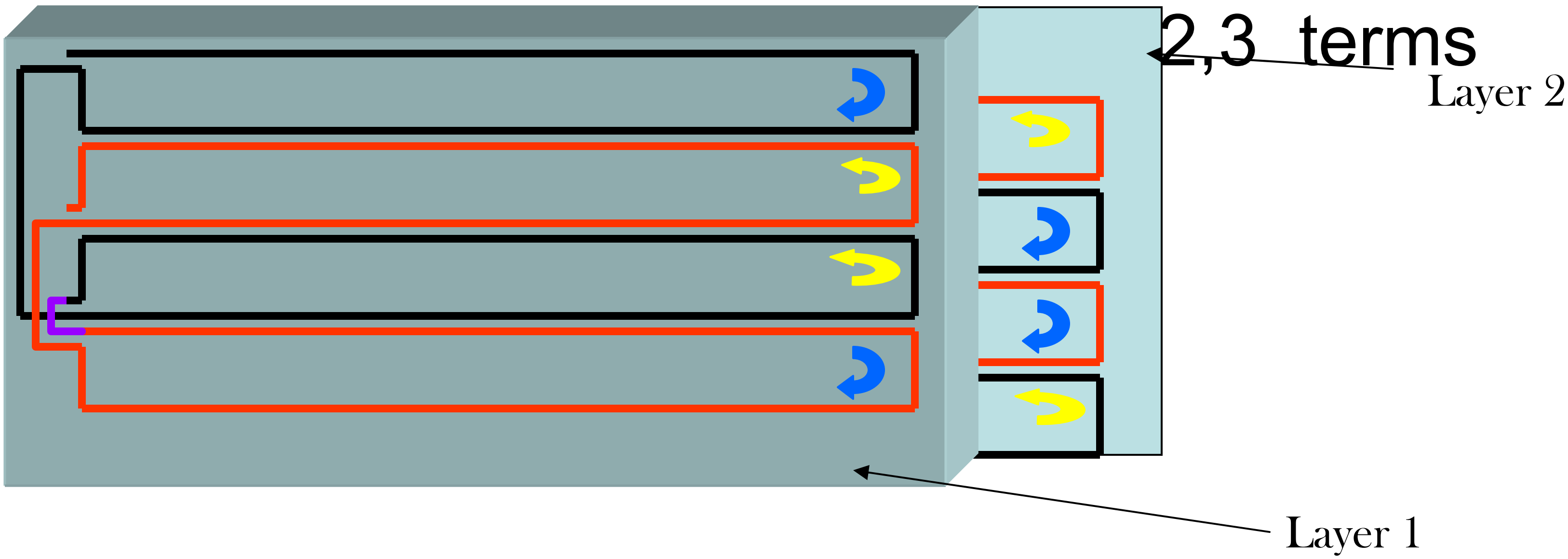
Use FFT of rotating probe signal and calculated sensitivities to find Fields

Applicable to all rotating coil data systems

T. Ogitsu, J. DiMarco, 1999

Dipole Quad Sextupole Bucking

- Combine 2 DQ buck layers with opposite handedness



Combined layer 1 loops buck dipole-quad, as do layer 2 loops.

Since layers 1, 2 measure gradient difference (sextupole),
bucking these two layers bucks sextupole in addition to dipole and quadrupole.

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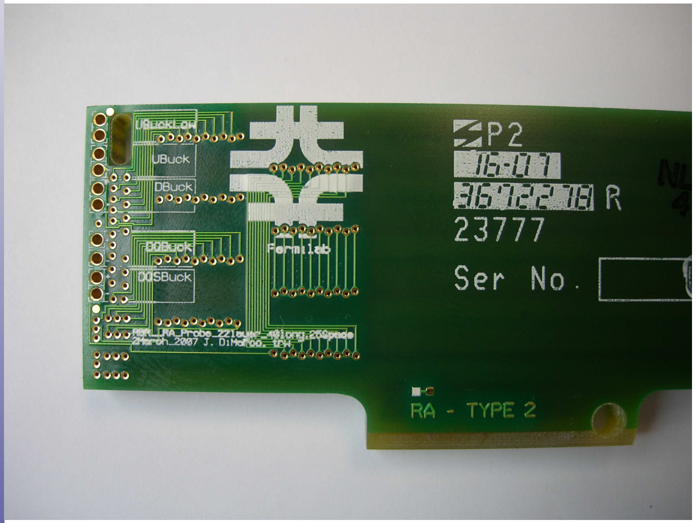
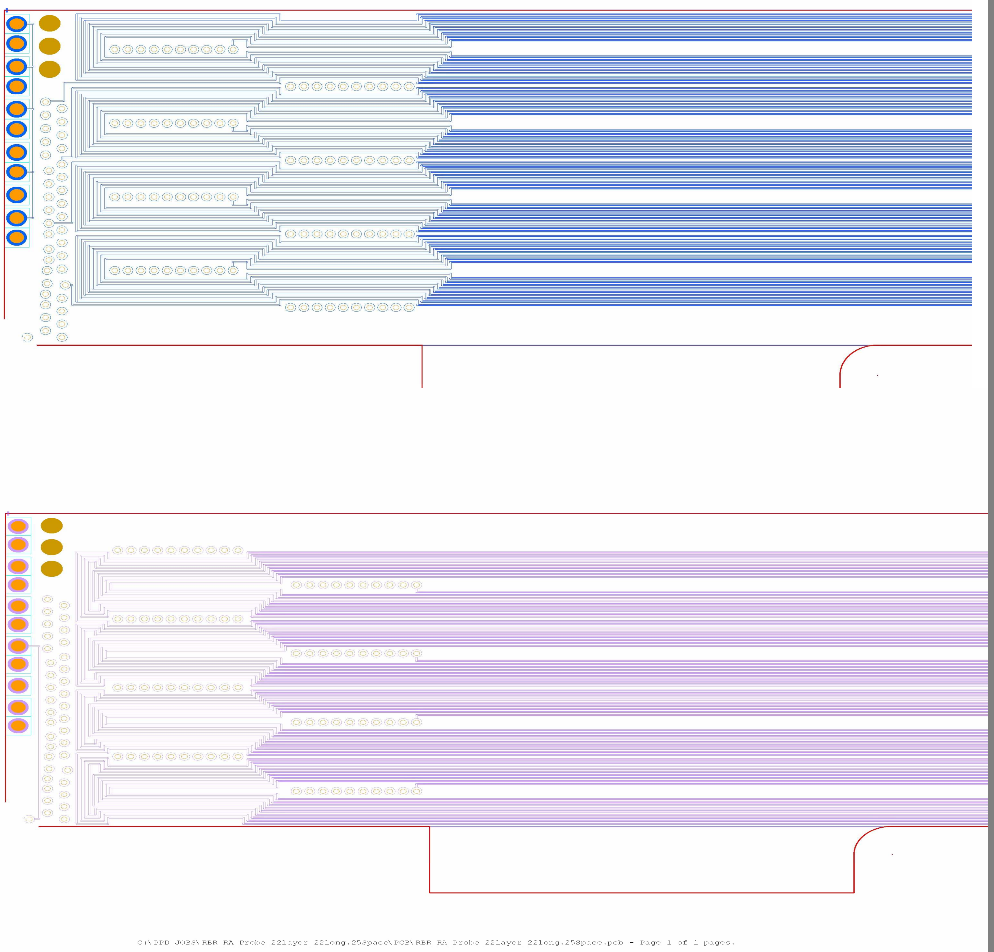
DQS Bucking Probe for BMA Fixed Coil Measurements





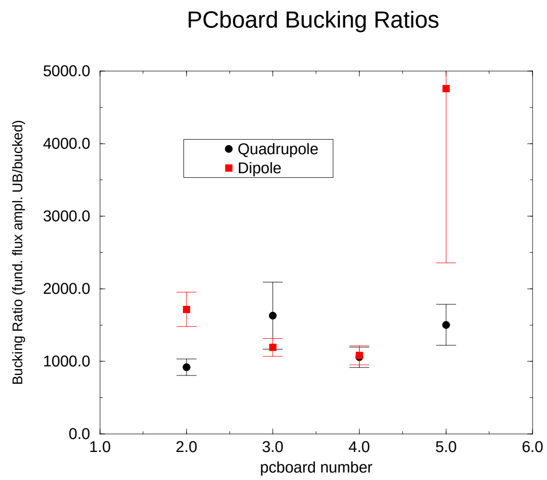
Fixed Coil Array Assembly

Circuit Board Construction, Joe DiMarco

Results:

Excellent bucking ratios

Low cost

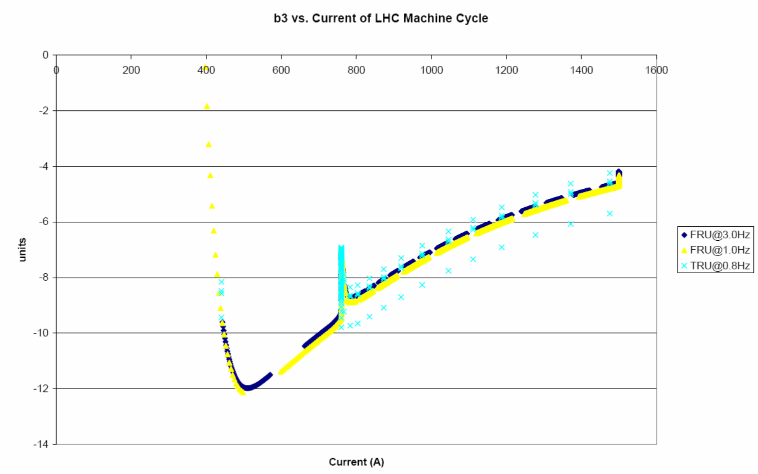


- 2 layer, 39mm: $10
- 30 layer, 39mm (with buried vias): $1500
- 22 layer long 40”: $400
- 48”: $4000
- Buried vias, layers, increase costs: to some extent also tight spacing of space/trace
- Some ‘setup’ fees – can be significant depending on job and company.

Fast Measurements, Juan Garcia-Perez

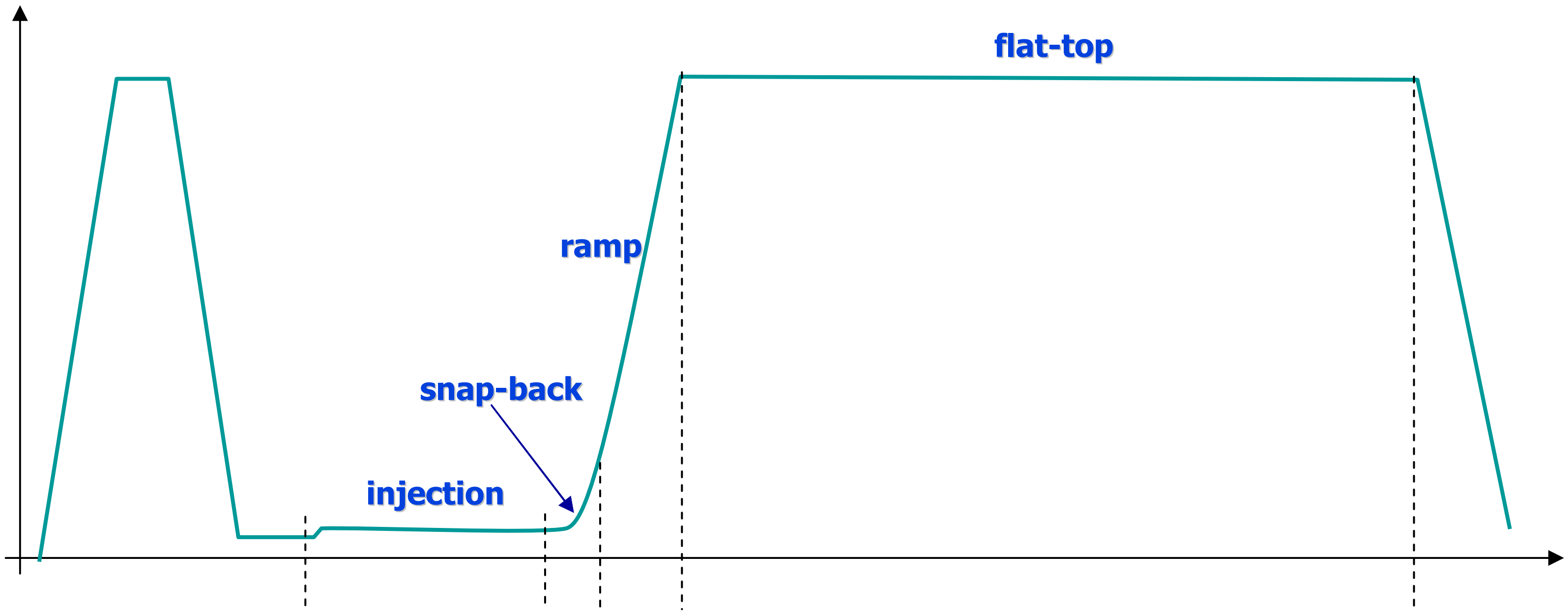
FAME Program
(FAst Measurement Equipment)

Improvements to measure magnets with higher bandwidth.



- Rotating coil mechanics improved
- New rotation units
- New digital integrators

different measurement systems are palnned for different parts of the cycle according to spec r



	injection	snap-back	ramp	flat-top
rotating	✓	✓	✓	✓
fixed coils			✓	
Hall probes		✓		
NMR	✓			✓

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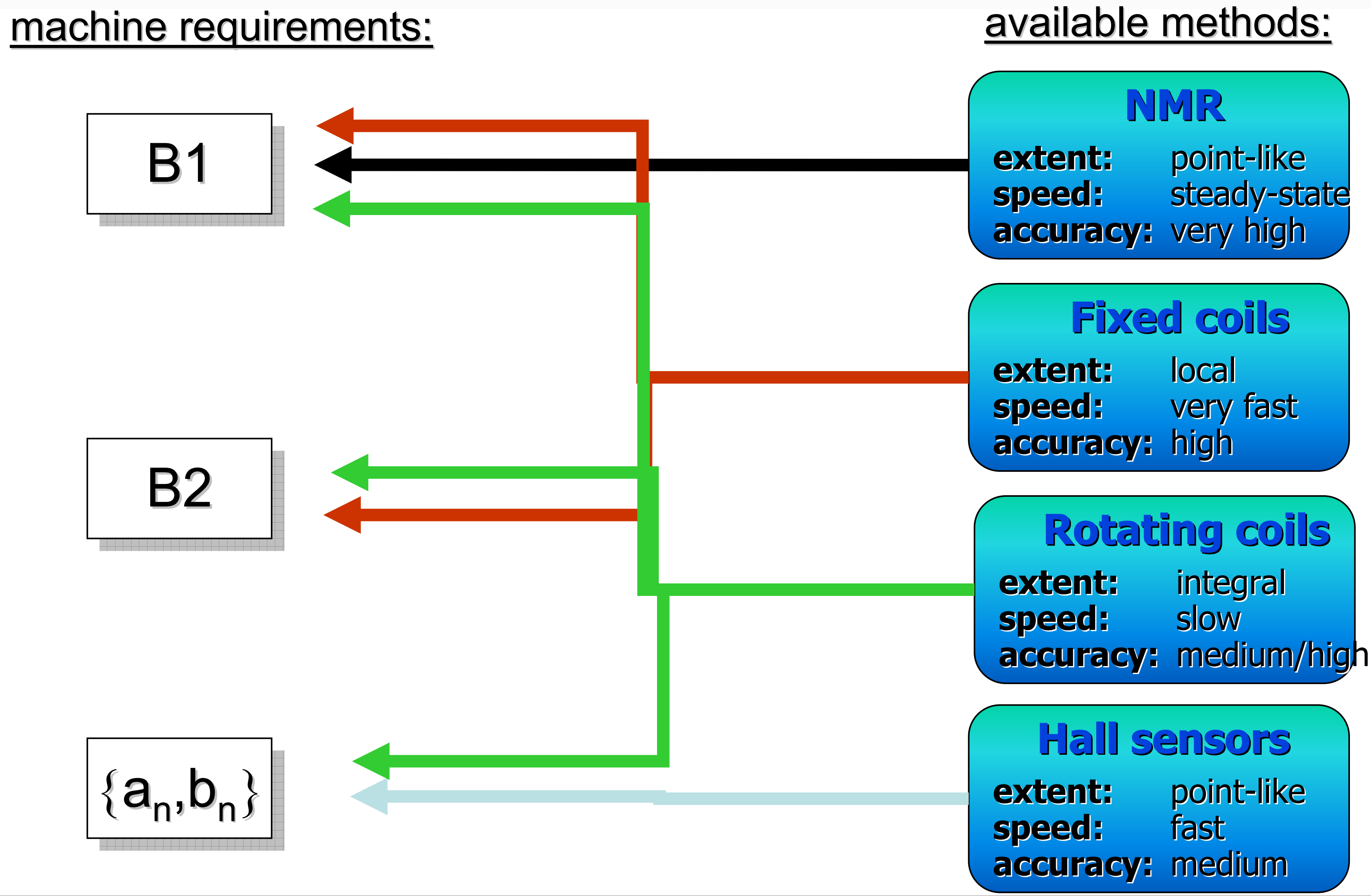
Overall FAME architecture



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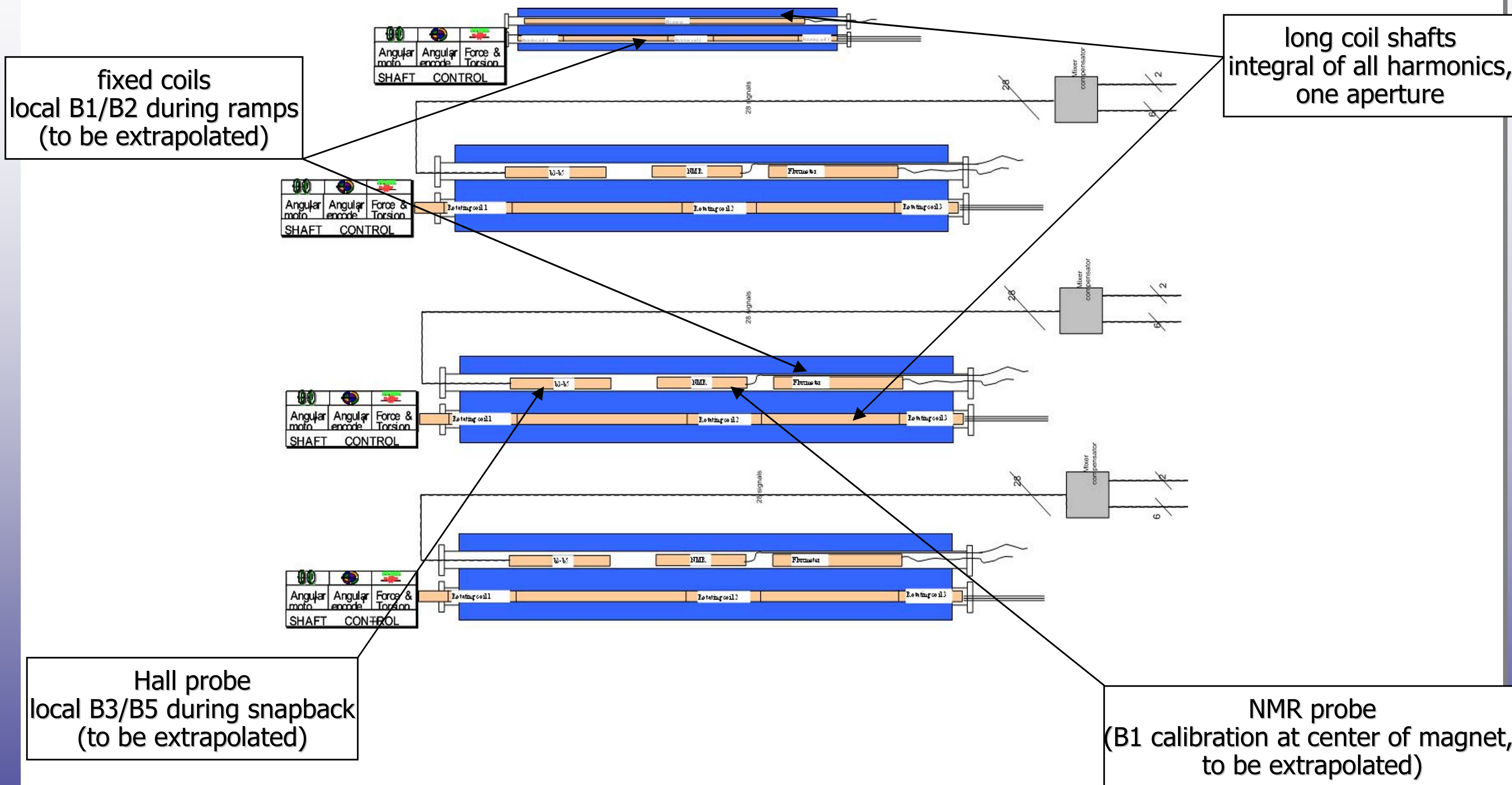
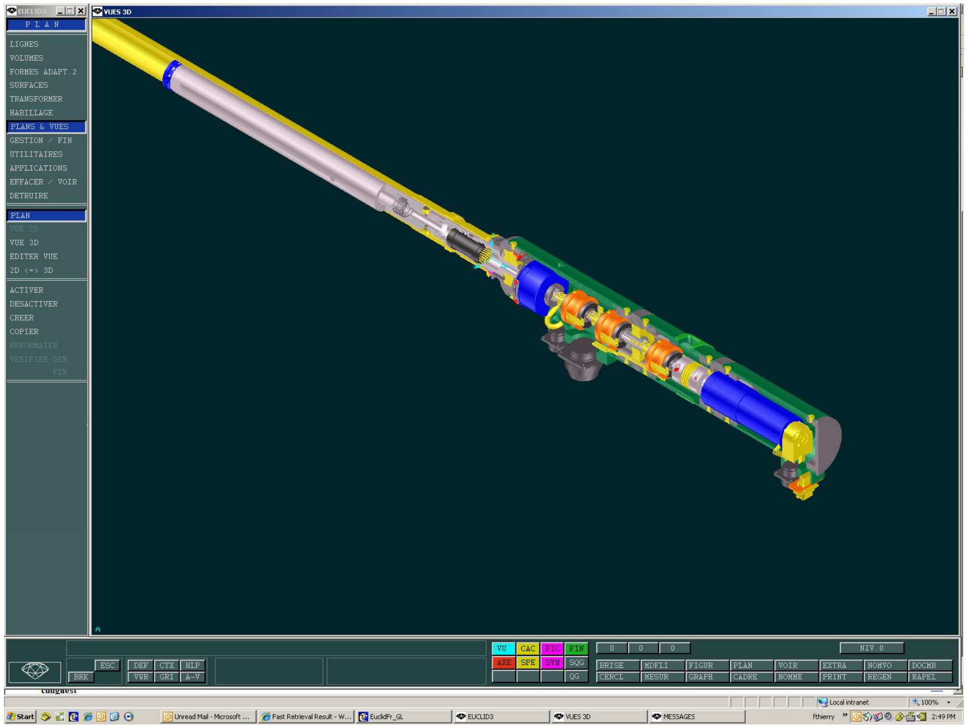


multiple instruments combined in parallel to overcome individual shortcomings

Rotating coils: developments needed

- Hardware
  - **Coil shafts:** modify existing shafts by connecting in series groups of contiguous coils (lower total channel count – 3 super segments).
  - **New shafts:** to reduce the signal amplitude due to high rotation speed and series connection of segments new coils with ¼ of # of turns (effective surface).
  - **Rotation unit:** New rotating unit lighter and with slip rings to allow continuous rotation in one direction at around 2-4 Hz limited by mechanical vibrations.
  - **Digital integrators:** faster ADC/DSP-based digital integrators.
  - **Acquisition system**: new real-time computer system for higher data throughput.
- Software
  - **Embedded code**: low-level logic to drive DSP integration (+ possibly harmonic analysis)
  - **Acquisition and control code:** real-time software to drive the instruments and to carry out continuous harmonic analysis
  - **Harmonics analysis:** new algorithm to increase precision during ramps, taking into account the variation of current with time (if necessary with sliding-window FFT for faster interpolation)
  - **Integration**: interface with overall FAME system


VUES 3D
P L A N
LIGNES
VOLUMES
FORMES ADAPT.2
SURFACES
TRANSFORMER
HABILLAGE
PLANS & VUES
GESTION / FIN
UTILITAIRES
APPLICATIONS
EFFACER / VOIR
DETRUIRE
PLAN
VUE 3D
EDITER VUE
2D <-> 3D
ACTIVER
DESACTIVER
CREER
COPIER

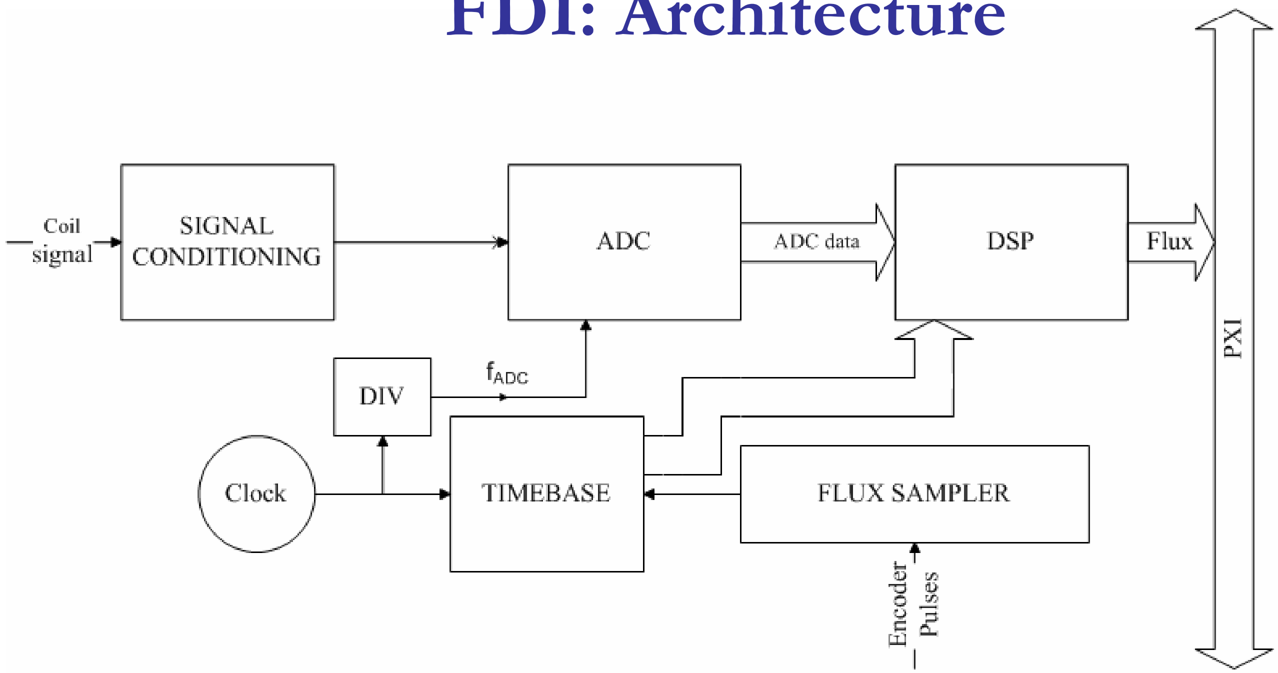
Fast Digital Integrator, Juan Garcia-Perez

Motivation:

New specifications

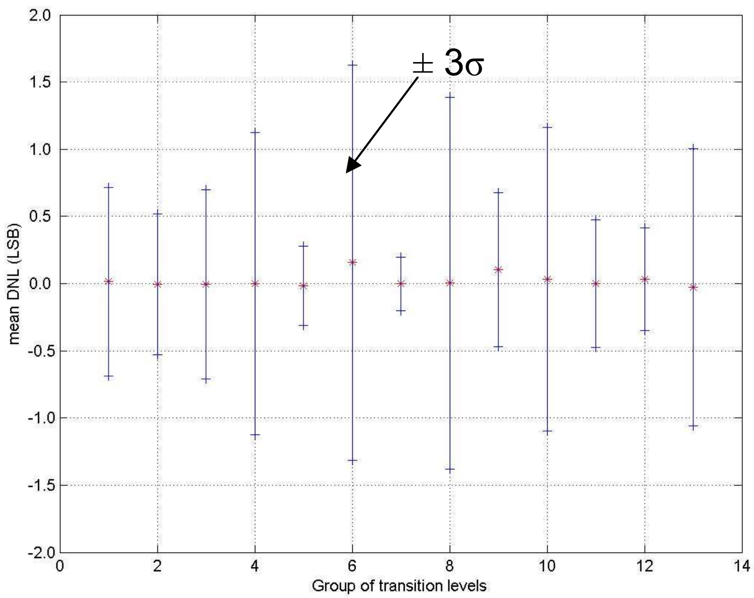
- *Increase in coil speed up to 8 Hz and more + continuous rotation*
- *Measurements on magnets in dynamic conditions with a ramp slope up to 1000 A/s*
- *Field harmonics measurements in real time in a fraction of second for on-line monitoring reference magnets*

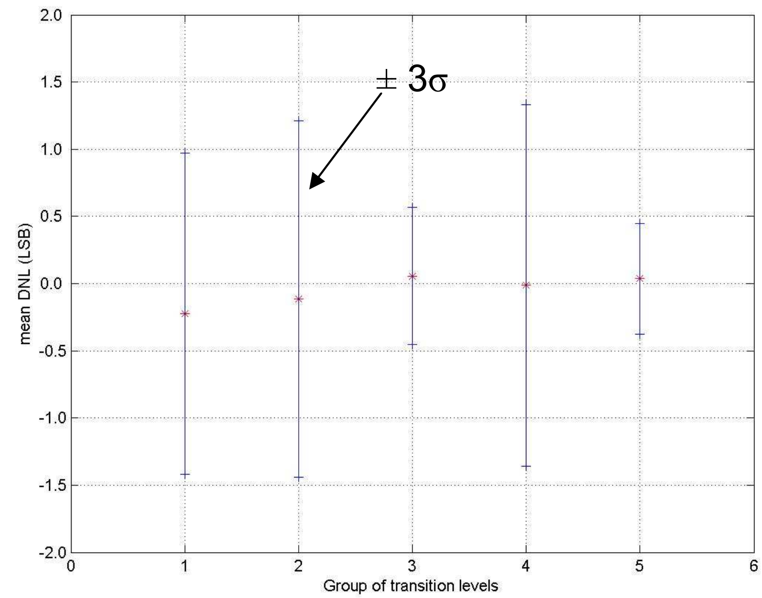
FDI: Architecture



- The input signal is conditioned by a programmable gain amplifier (PGA), with offset and gain self-calibration
- The conditioned signal is sampled and quantized by an ADC
- A DSP carries out the integration algorithm on-line
- Trigger events are provided by a flux sampler and measured by a time base
- Flux samples are sent to a host PC via PXI bus

Results of Static Tests on prototype (I)





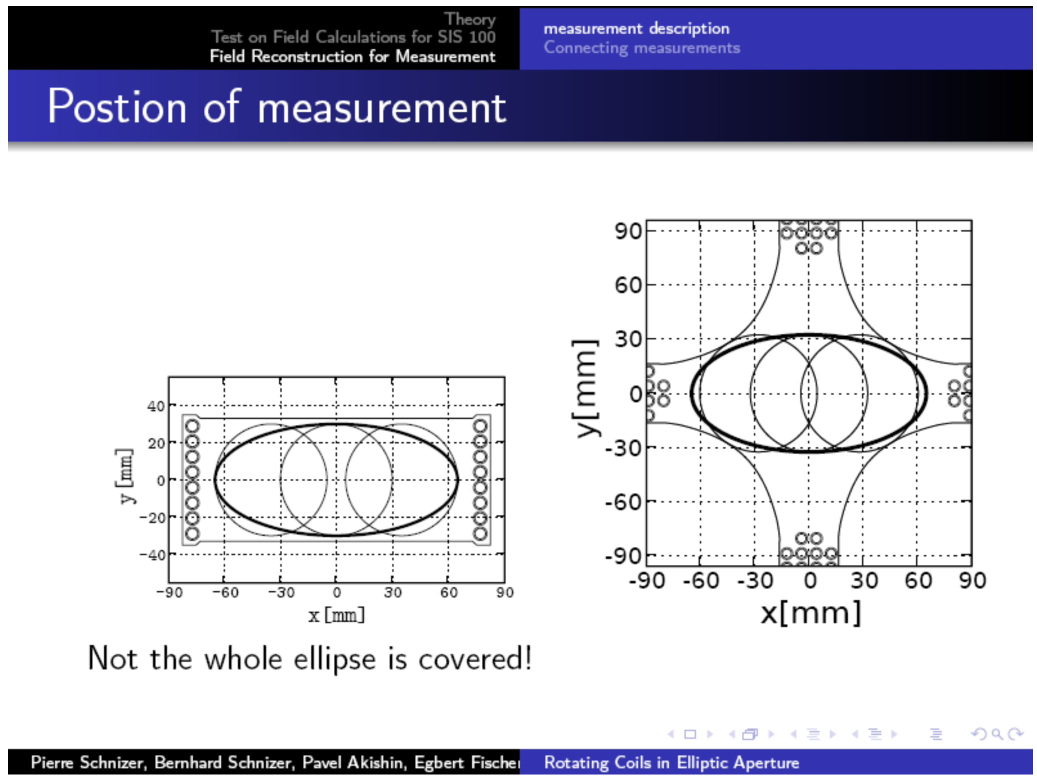
- PDI
  - Trigger frequency: 512 Hz
  - LSB: 10.240 mV
- FDI
  - Sampling rate: 625 kS/s
  - LSB: 38 μV

Field Reconstruction, Pierre Schnizer

Basic Problem:

Magnet geometry is
not matched to rotating
coil geometry.

How to express overall field
using multiple measurements?

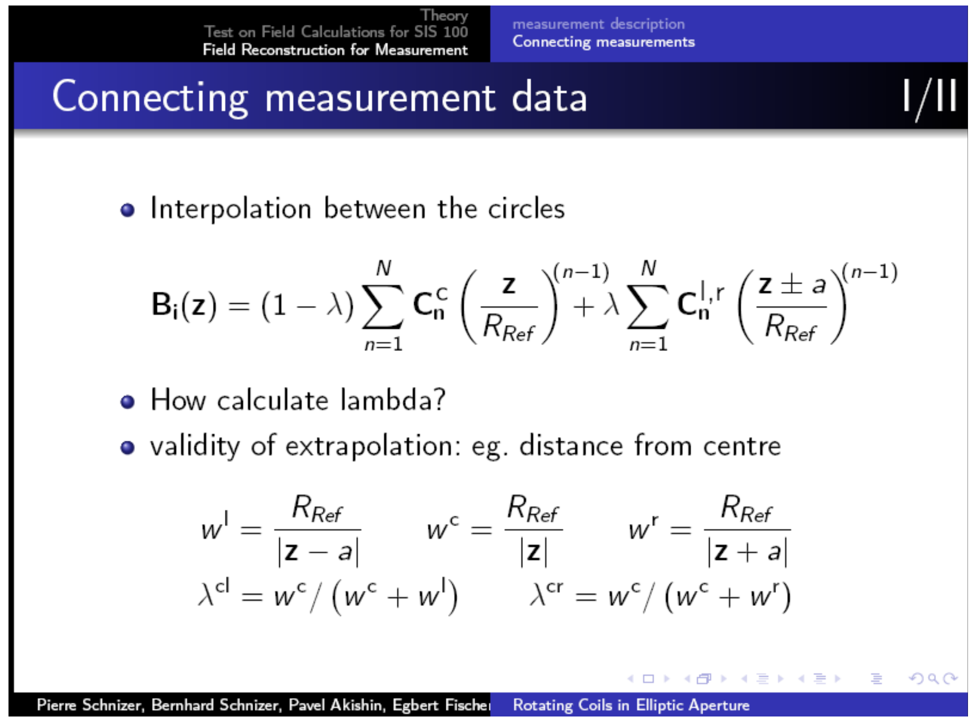


Field Reconstruction, Pierre Schnizer

Solution:

Use weighted fits to the measurements.

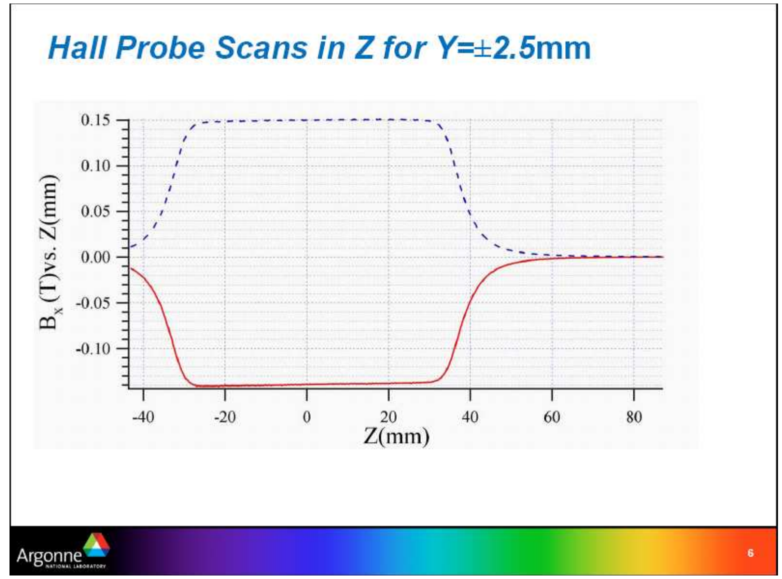
Use elliptical coordinates as global coordinates to better match the magnet geometry.

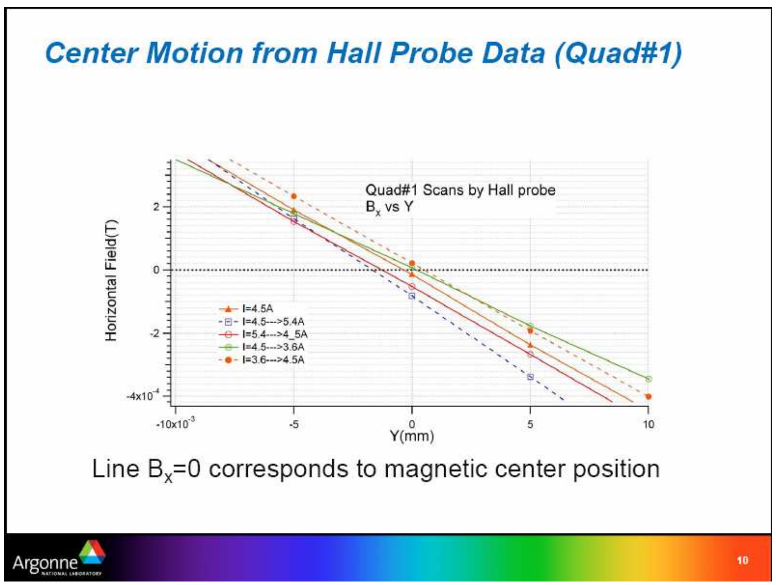


Alternate Techniques, Isaac Vasserman

Hall probe scans give detailed field shape information.

Can be used to calculate the integrated gradient.

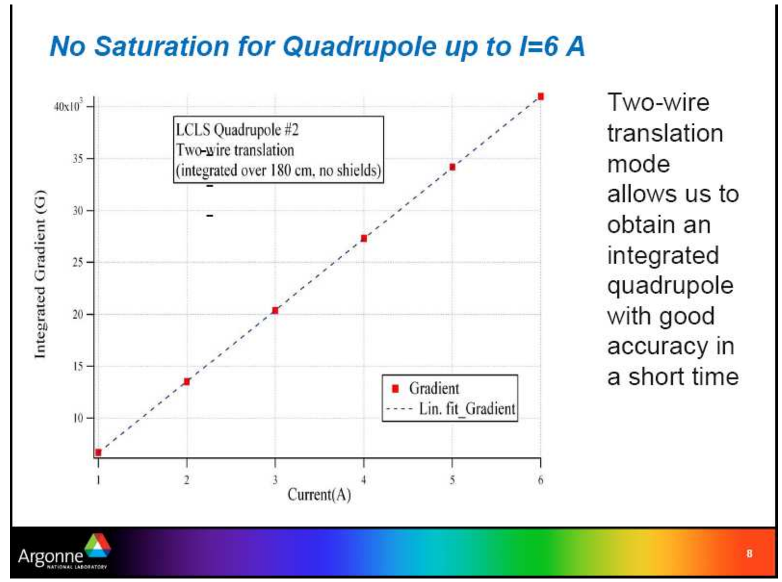


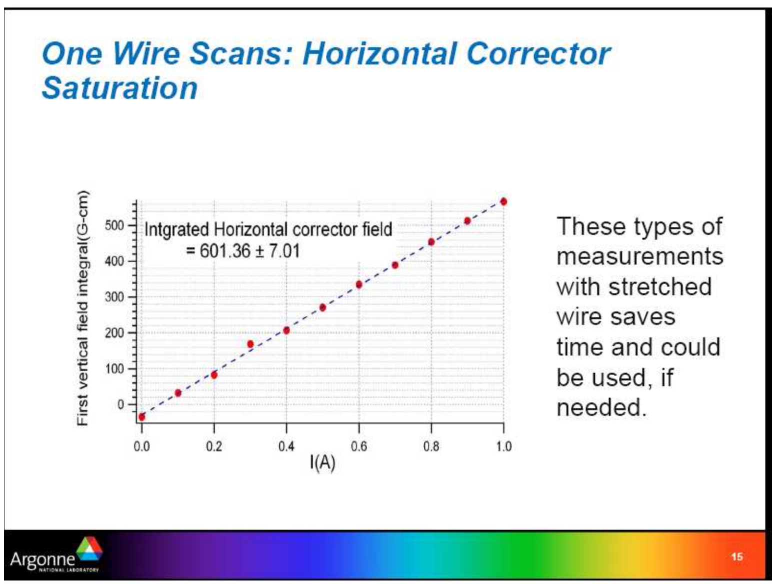


Hall probe scans can give the magnetic center.

Alternate Techniques, Isaac Vasserman

Wire scans give magnet strength.
Can also be used for magnet center.





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