Designing a Magnetic Measurement Data Acquisition and Control System with Reuse in Mind: A Rotating Coil System Example

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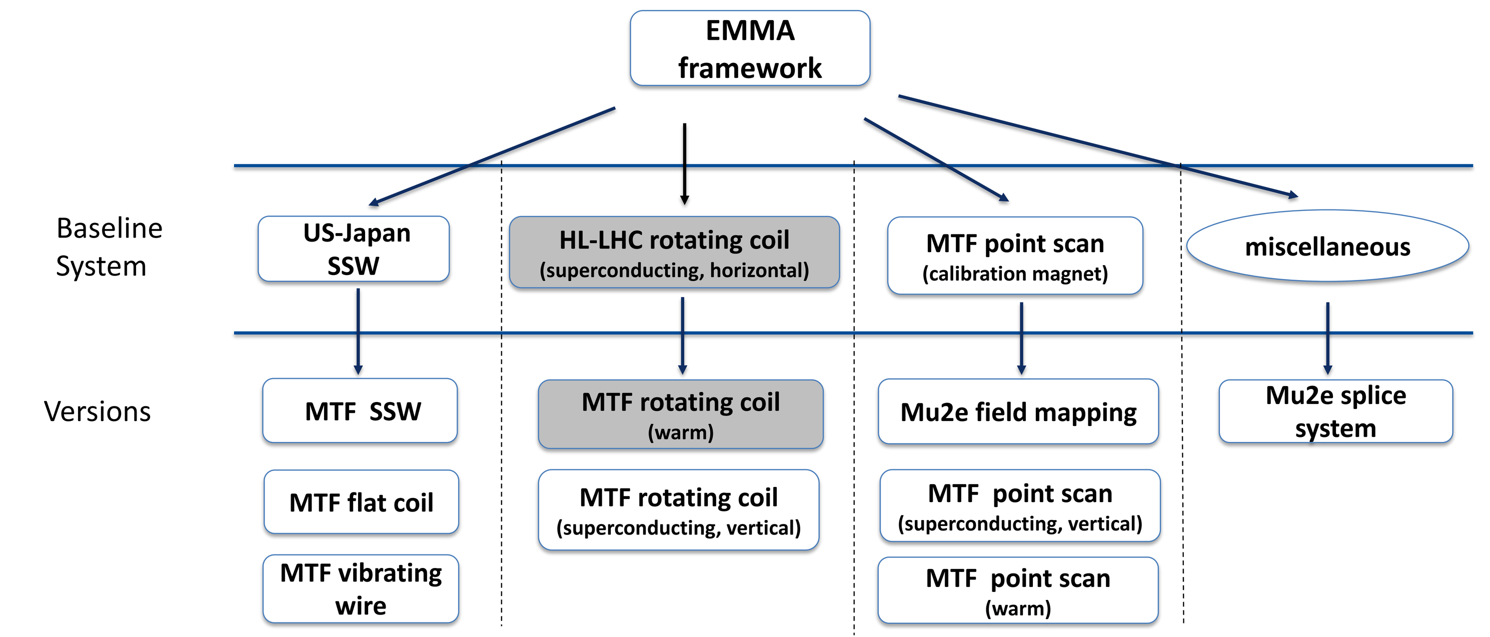
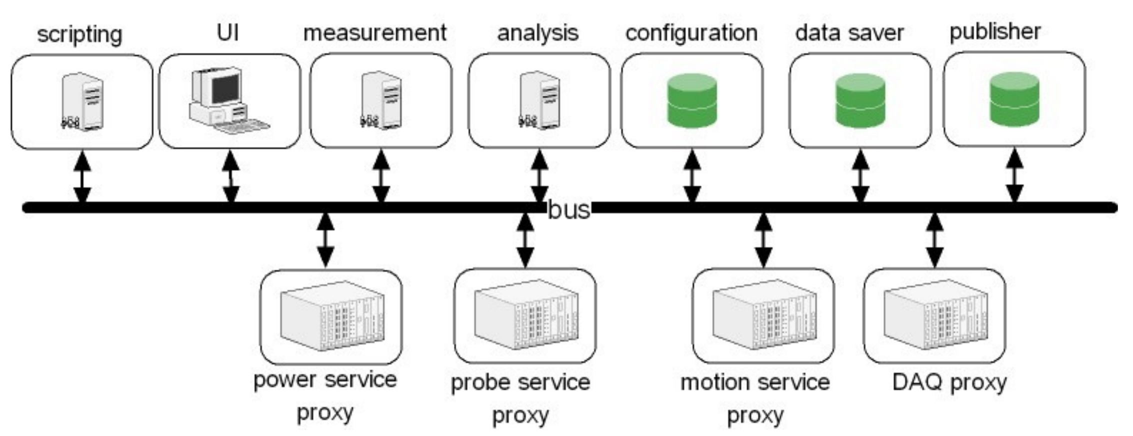
Measurement System Family

The software **product line method** is used to develop a **family** of measurement systems. These systems are based on a common architecture, which promotes reuse and allows for configuring specific measurement systems from the set of reusable components.



Family of Magnetic Measurement Systems, including rotating coil systems.

EMMA Framework



Software bus with connected local and remote components

The EMMA framework is an example of **architected reuse**, where a family of applications (measurement systems) is built based on a common design and implemented on a common framework.

EMMA is a **component-based framework**, where applications are constructed by assembling them from loosely coupled, standardized components. Its **message-oriented architecture** is implemented on a publish-subscribe software bus, which supports local and remote communication of components, with local components connected to the bus by message queues and remote components via socket-based TCP/IP.

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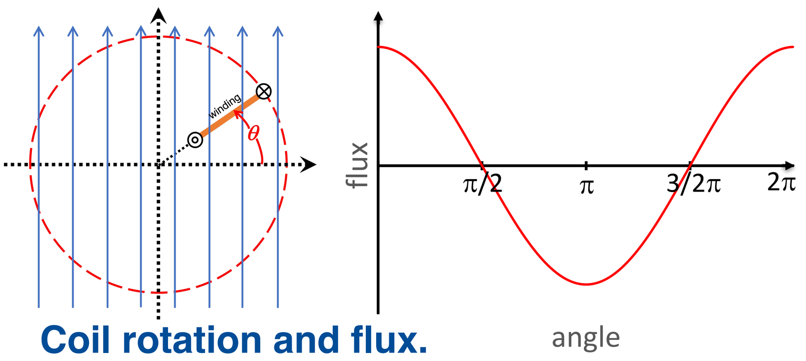
Rotating Coil System

A rotating coil (loop of wire) measures the changes of the intercepted flux. A digital integrator externally triggered by an angular encoder measures the differences in flux, Φ, between two incremental angular positions (1). The multipoles of the field are directly given by the Fourier analysis coefficients Ψ_n of the integrated voltage over a coil turn (2).

$$\Phi_{n+1} - \Phi_n = -\int_{t_n}^{t_{n+1}} V(t)\cdot dt \quad (1)$$

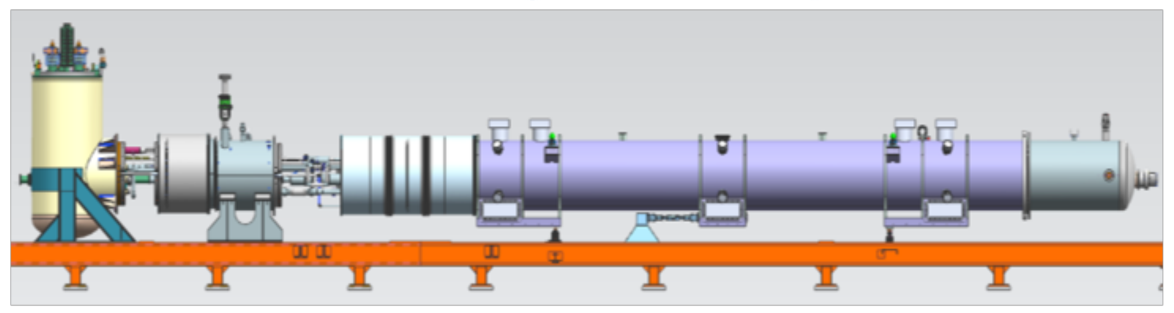
$$\Psi_n = K_n \cdot (B_n + iA_n) \quad (2)$$

V is voltage, A_n, B_n are skew and normal multipoles of the field, and K_n is a coil sensitivity factor for the n[th] harmonic order.



Coil rotation and flux.

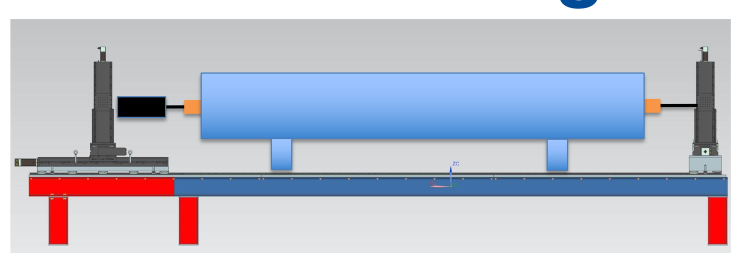
"Cold" Rotating Coil System



Rotating coil system for HL-LHC AUP

- HL-LHC AUP project
- LQXFA0, quadrupole, physical length = 10.1m, superconducting, (contains 2 MQXFA magnets of coil length 4.5m), I_{max} = 16.53 kA, I_{nom} = 16.23 kA, field gradient G_{nom} = 132.9 T/m
- Measurements: strength, multipoles, field direction
- Hardware: translation table, EDI integrator, mole probe (3 coils), laser tracker, Aerotech 1-axis controller (rotation)
- Integration: IFIX cryogenic control system, power supply control

"Warm" Rotating Coil System

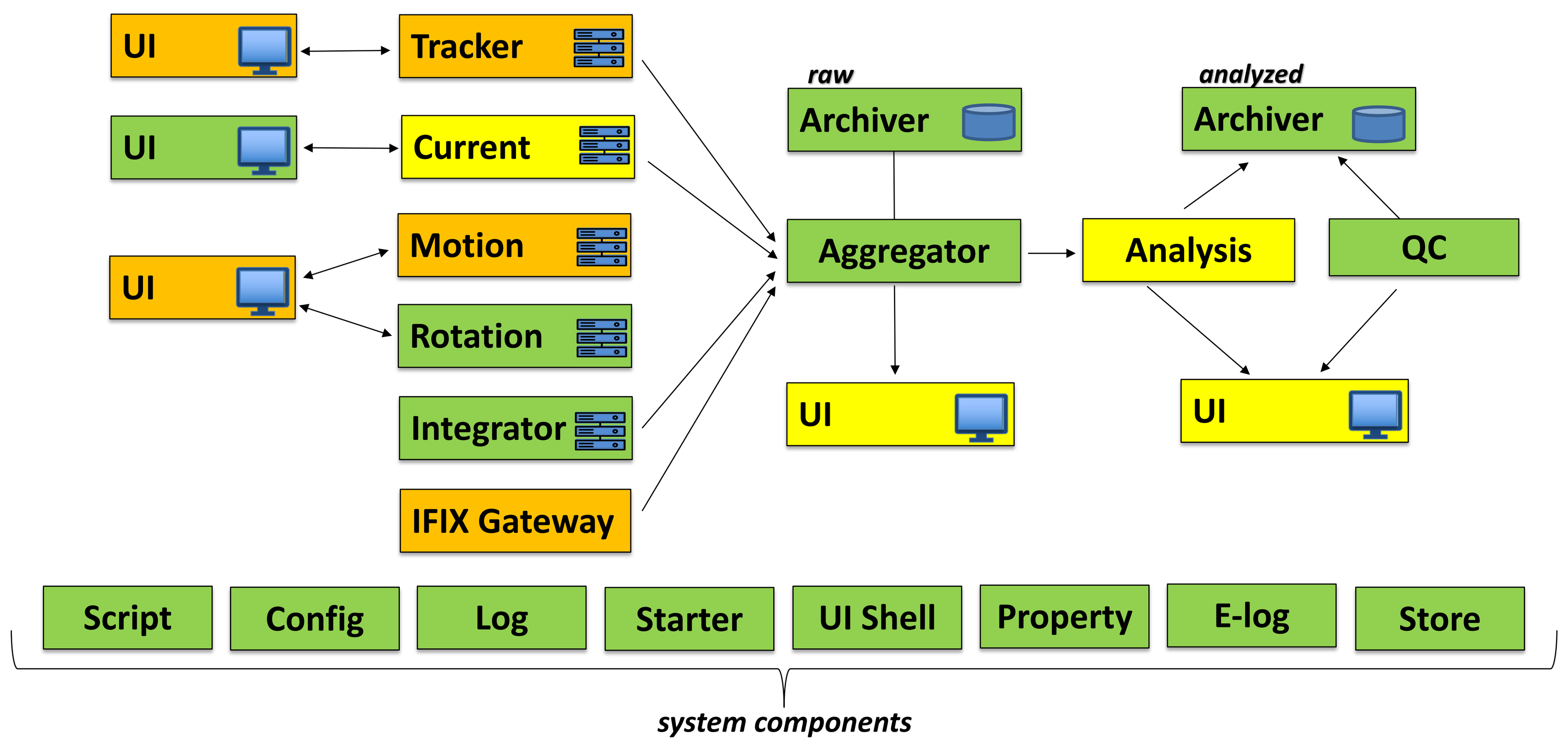


Rotating coil system for Fermilab accelerator complex

- Fermilab Accelerator Complex, Main Injector
- IQC quadrupoles (IQC241, IQC242, IQC243), 2.54 m, room temperature, I_{max} = 4 kA, I_{nom} = 3.63 kA, G_{nom} = 19.6 T/m, Integrated strength = 49.8 T-m/m
- Measurements: strength, multipoles
- Hardware: Aerotech 2-D positioning tables, EDI integrator, Morgan probe (9 coils), Aerotech rotation
- Integration: power supply control

Reuse

- **Design reuse**: architecture, component design and template
- **Implementation reuse**: framework and system components
- **Domain specific reuse**: reusable components (DAQ, instruments, data saving, data processing, etc.), components extensible via plugins and reengineering of similar components.



Rotating Coil System Components (complete reuse , partial reuse , specialized)

Flexibility

Variability	Implementation
Different measurement procedure	different scripts
Measurement parameters	script parameters
Differences in DAQ hardware	different components or plugins
Different data to archive	universal archivers
Different visualization of data	configuration and plugins
Multi-computer systems	distributed components
Different analysis	plugins with algorithms in MATLAB, LabVIEW, or C
Component behavior	component properties and decision tables

Addressing variability in EMMA-based measurement systems

Summary

A plethora of test and measurement systems are needed to fulfill the mission of the Fermilab Magnet Test Facility. Using the product line method of producing a family of magnetic measurement systems provides effective reuse and built-in flexibility, which allows for accelerated development, increased dependability, lower development costs and improved project predictability (reduced risk). The two presented rotating coil systems prove that even dissimilar test systems can be successfully built with a high level of reuse.