Power Converters

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Outline

LHC:

1. Power Converter
    1. Changes during LS2
    2. R2E-LHC600A
    3. R2E-LHC4-6-8kA
    4. Other

2. FGClite controls
    1. Introduction/failure scenarios
    2. Interlocking logic
    3. Observed failure statistics

3. Software
    1. API for PM tools
    2. Software validation process
    3. Future API changes

SPS:

1. BIS concentrator

LHC Power Converters

Typical use	Type	Current	Voltage	Location	Quantity
Main Dipoles	RPTE	13kA	180V	UA	8
Main Quads	RPHE	13kA	18V	UA	16
IPD, IPQ, IT	RPHx	4-6-8kA	8V	RR, UA/UJ	189
600A Multipole correctors	RPMBx	600A	10V	RR/UL, UA/UJ	400
Orbit correctors	RPLB	120A	10V	RR/UL, UA/UJ	290
Orbit correctors	RPLA	60A	8V	ARC	752
Saturn_2s	RPADO	850A	700V	SR	4
RPMC 600A-40V	RPMC	600A	40V	UJ/TZ	37
Other warm circuits	RPTx			UA/UJ/TZ	26
Σ					1722

≈1050 in LHC radiation areas

R2E-LHC600A

R2E-LHC600A-10V replacing LHC600A-10V converters

- Replace 104 existing LHC600A-10V in exposed areas (RR13, RR17, RR53, RR57,RR73 & RR77), by new rad-tolerant version, for LS2.
- The design solves known electrical issues, to improve their availability for LHC (& HL-LHC) operation, through a redundant design.
- The power source delivers the same or improved electrical performances.
- The power converter keeps the same overall dimensions.
- The R2E converter control is based on a FGClite (deployed in LS2)

Domain	Old replaced design	New LS2 / R2E design
Radiation	Not radiation tolerant	Solved
Converter Controller	FGC2	FGClite
0V crossing point perturbation	Output current perturbation at 0 V	Solved
Availability	No active redundancy	Solved
MTTR (Time to Repair)	Design not sufficiently modular	Solved
Converter protection	Fast Abort Chain, Earthing, Crowbar, State Machine, Over current	No change
PIC interface	Fast Abort, Powering Failure, Power Permit, PC Discharge Request	No change

R2E-LHC4-6-8kA replacing LHC4-6-8kA converters

- Replace 60 existing LHC4-6-8kA in exposed area (RR13, RR17, RR53, RR57), by new rad-tolerant version, for LS2.
- Converter new design is based on same technical specification than old one.
- The power source delivers the same or improved electrical performances.
- The power converter keep the same overall dimensions.
- The converter control is now based on a FGClite.

R2E-LHC4-6-8kA

Domain	Old replaced design	New LS2 / R2E design
Radiation	Not radiation tolerant	Solved
Converter Controller	FGC2	FGClite
Free Wheeling Diode Warning Management	False warning triggered	Solved
Water Fault Management (Sub-converter level)	Water fault limitation	Solved
Electrical Performances (Input Phase Loss)	AC mains event issue	Solved
EMC -Burst (Cabling)	EMC Immunity issue	Solved
Converter protection	Fast Abort Chain, Earthing, Free Wheeling Diode paths, State Machine, DC cable water fault, thermo-switches, over current	No change
PIC interface	Fast Abort, Powering Failure, Power Permit, PC Discharge Request	No change

FMCM trips in 2016 & mitigation

RD1/RD34 replaced with Saturn converters during EYETS'16-17.
This helped to significantly reduce FMCM triggers: 23x (2016) vs. 9x (2017) vs. 3x (2018).
RQ4/RQ5 will not be consolidated during LS2 as no need
was reported from TE-MPE after a review in Evian.

7 TeV Operation

All circuits designed & tested for ultimate LHC conditions.
No impact on the availability is expected.
Increase from 4TeV to 6.5TeV operations did not produce sizeable effect on the failure rate.
LHC4-6-8kA & LHC13kA power modules for RQF/RQD already used in ultimate conditions in ATLAS.
Sensitivity to electrical glitches might slightly increase at 7TeV.

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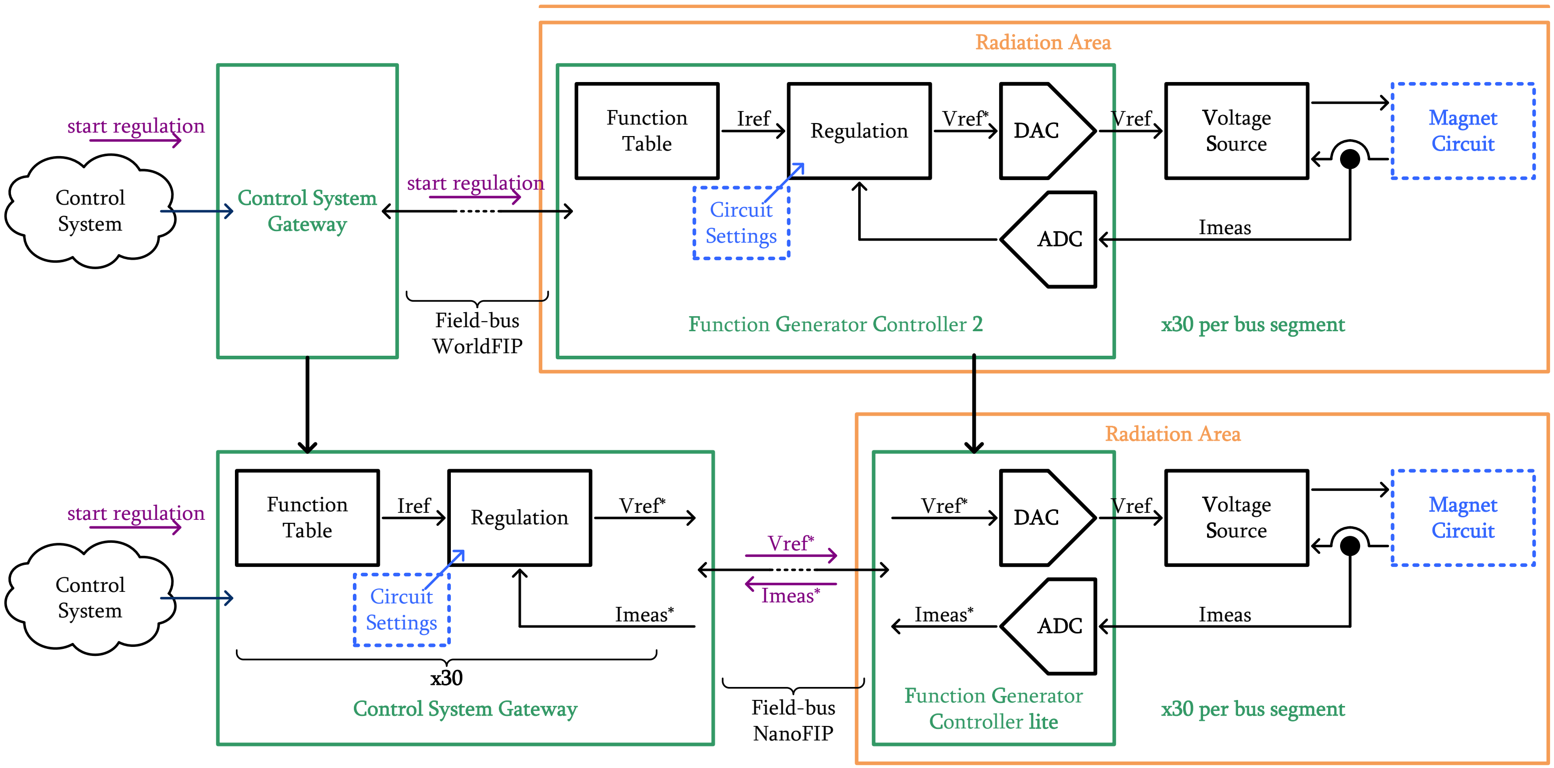
SPS:

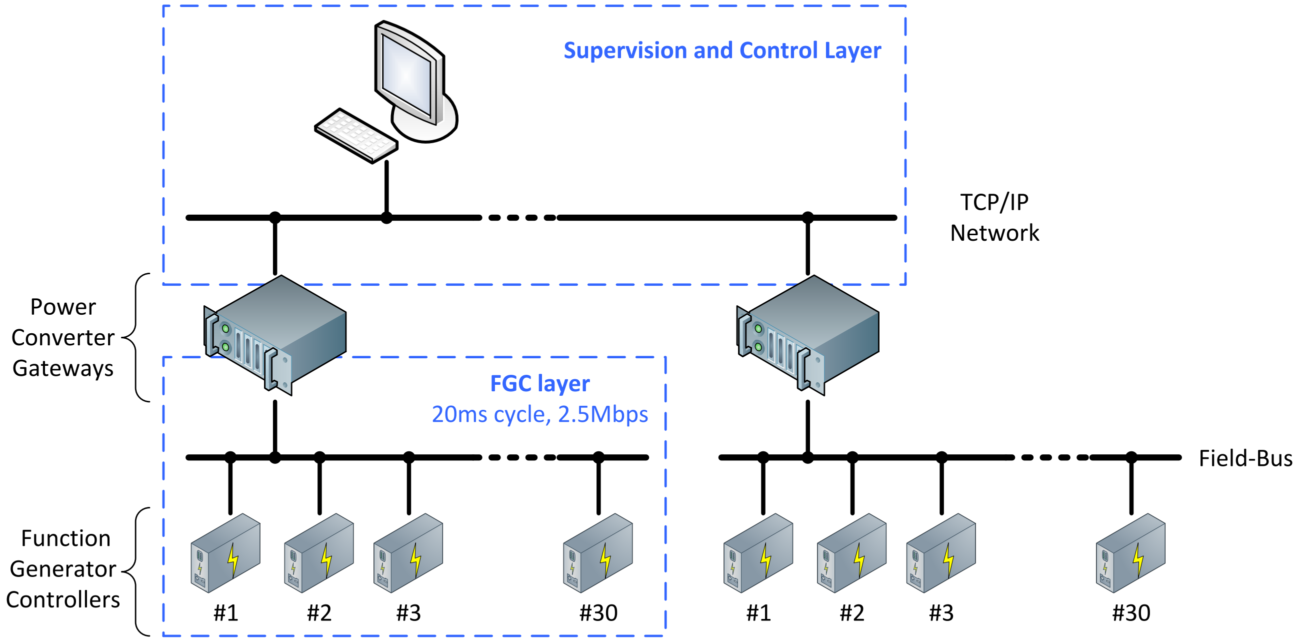
1. special features: BIS concentrator (Ben)



Dedicated design methodology:

1. No microcontrollers/DSP as computationally intensive tasks moved to the gateway
2. Extensive radiation testing to select/validate all electronic components
3. **Highly available Gateway/FGClite communication required**

Reliable communication infrastructure



FGClite infrastructure (**TE-EPC**):

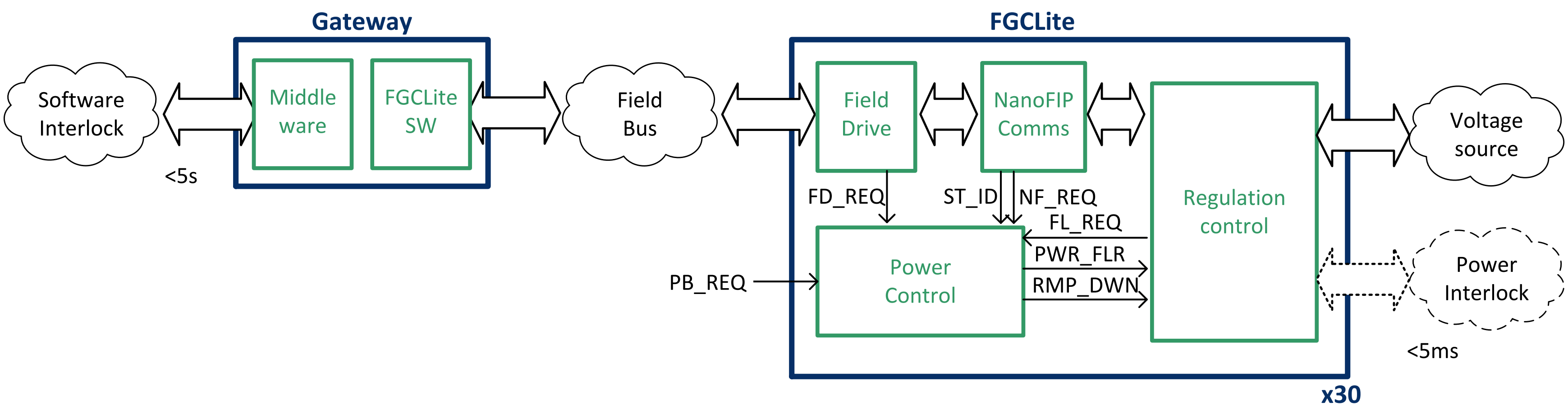
1. Robust FGClite hardware
2. Robust Gateway software and hardware

World FIP (**BE-CO**):

1. FGClite/Gateway communication modules
2. Robust repeaters, cabling, etc…

FGClite & Machine Protection Links

FGClite system – links with machine protection



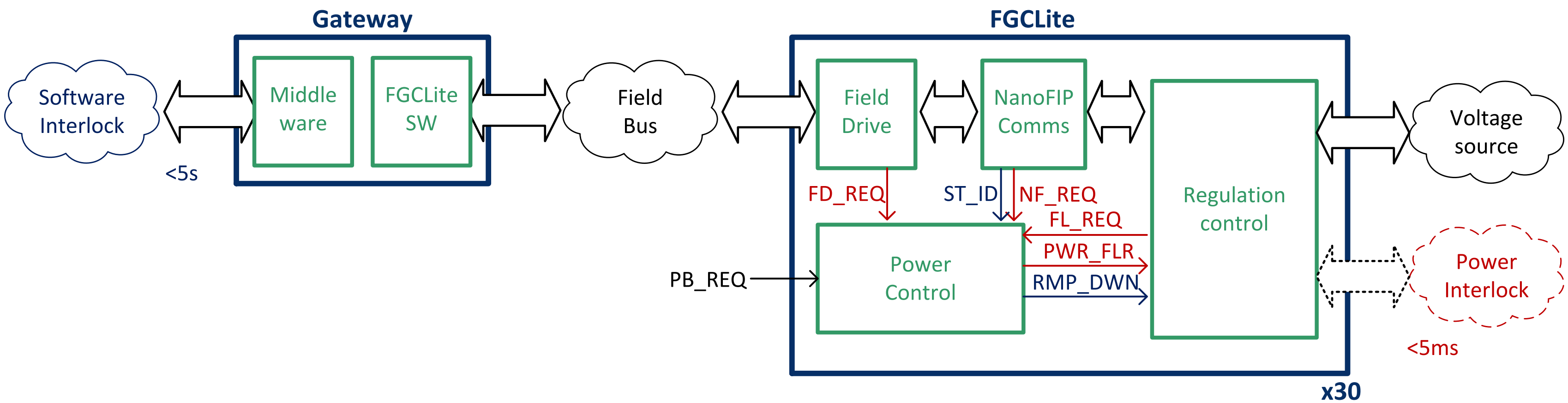
FD_REQ: Field Drive Request
NF_REQ: NanoFIP Request
FL_REQ: FGClite Request
PB_REQ: Push Button Request

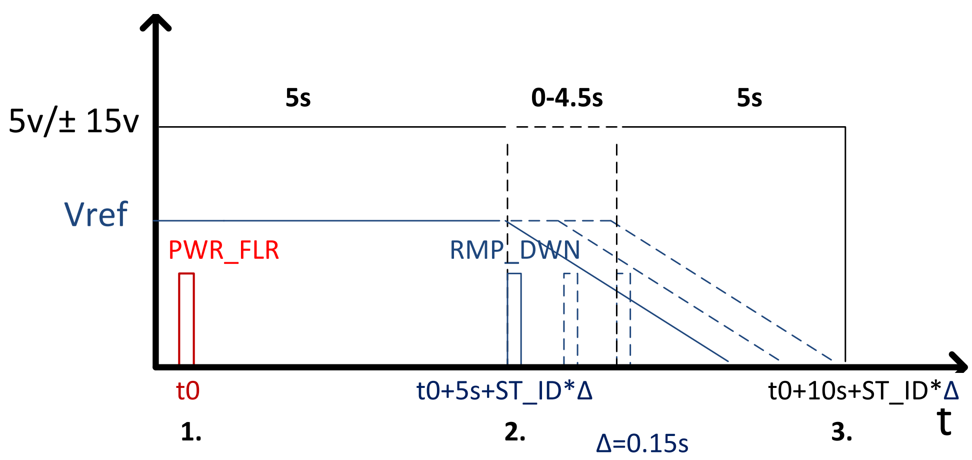
Failure scenarios:

Gateway SW fails or Fieldbus communication fails: **FD_REQ** (up to 30x FGClites)
FGClite transmission/internal failure: **NF_REQ** (single FGClite)
FGClite reception failure : **FL_REQ** (single FGClite)

Reviewed by MPP in Apr 2014, tested in A7 in May 2016, tested in the LHC TS1’2017

Remote Power Cycle (FD_REQ, NF_REQ, FL_REQ)





Procedure:

1. Communicate PWR_FLR
2. Maintain Vref (SIS time to react)
3. Start ramping down (spread time to avoid fast orbit changes)
4. Ramp down (to avoid QPS trigger) & switch off.

In the case of LHC60A Vref is not ramped down. The drift of current is compensated by the OFB.

LHC60A Operations feedback

No HW failures observed during 2 year period on 756x FGClites in the LHC60A

Couple of identified failure modes not impacting operations

Failure	2017	2018	Comments
I_MEAS	5x		Masked in software since Sep 2017 **not impacting operations**
V_OVER_RIPPLE	3x	3x	Noisy **BPM** New failure mode compared to the FGC2 that was more robust against noisy BPMs

Frozen gateway problems in 2018

No reported problems to EPC, as far as EPC knows that frozen gateway did not cause the complete FIP network failure causing a trip of full FIP segment

Extremely high field-tested reliability of the FGClite HW
No changes planned during the LS2 on the LHC60A CODs

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Post Mortem Data during Run 1 and Run 2

FGC2s, FGClites (since 2017) and FGC3s (since 2018) provided post mortem data to two PM systems:

- Original “PMX” PM service – obsolete
- Newer “PMD” PM service

During LS2, FGCs will stop using the original “PMX” PM service and will continue to send the core set of signals to the “PMD” Service.

The FGC classes guarantee to always supply this core set of signals. They will be documented in 2019 and frozen as the guaranteed PM API for FGC classes in the LHC.

FGC Software Validation

- New FGC software versions are tested in simulation and with converters in EPC test halls before deployment.
- After the difficulties with the introduction of the FGClites, it was agreed that operators would prepare checklists to perform after software updates, either during a technical stop, YETS or long shutdown.
- In the LHC, this has been automated with a sequence that was used successfully to validate the FGClite software in February 2018 and this validated version then ran for the whole of the 2018 physics run.

Future API Changes

- The "API" of an FGC class is multifaceted:
    - Properties
    - Published data
    - Post mortem data
    - Alarms

- Many important property changes will happen in LS2, to try to align the properties for different classes that do a similar job.

- Future API changes will try to reduce the impact on systems using FGCs or FGC data.

- A core set of operational properties will be defined and documented in LS2 and this will be frozen as much as possible into the future.

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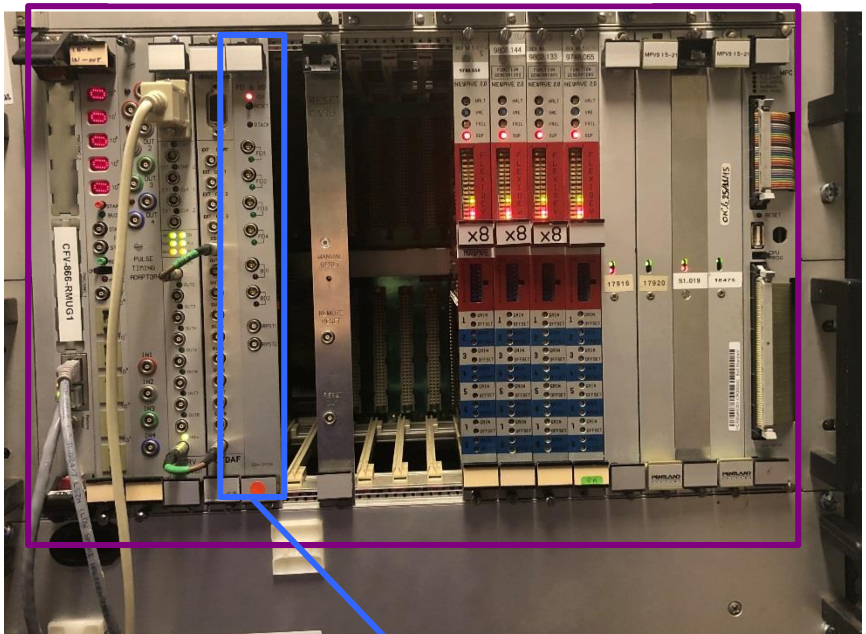
What does SPS Converter Controls Consolidation Look Like?

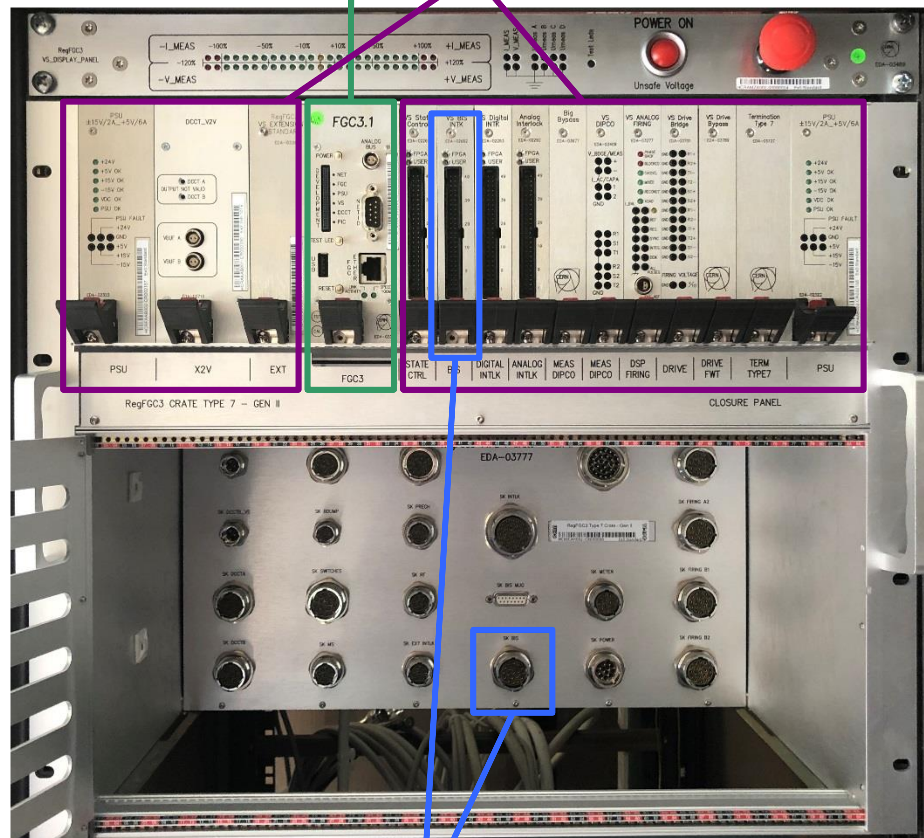
Legacy → **Consolidated**

MUGEF (VME)



Fast Extraction Interlock → Beam Interlock System

FGC3 RegFGC3



VS Beam Interlock → SK BIS → Beam Interlock System

MUGEF:

Centralised controller can drive **64 power converters**

Embedded **Fast Extraction Interlock** (FEI) board can drive
4 CIBU interfaces from one MUGEF

e.g. 1 MUGEF + 1 FEI = 64 interlocked converters, 4 CIBU

FGC3 + RegFGC3:

Individual controllers each can drive **1 power converter**

Embedded **VS Beam Interlock** board can drive **4 CIBU** from one converter

e.g. 1 FGC3 + 1 VS Beam Interlock = 1 converter interlocked, 4 CIBU

Issue

Problem: Need **many more inputs** to the Beam Interlock System for the same function

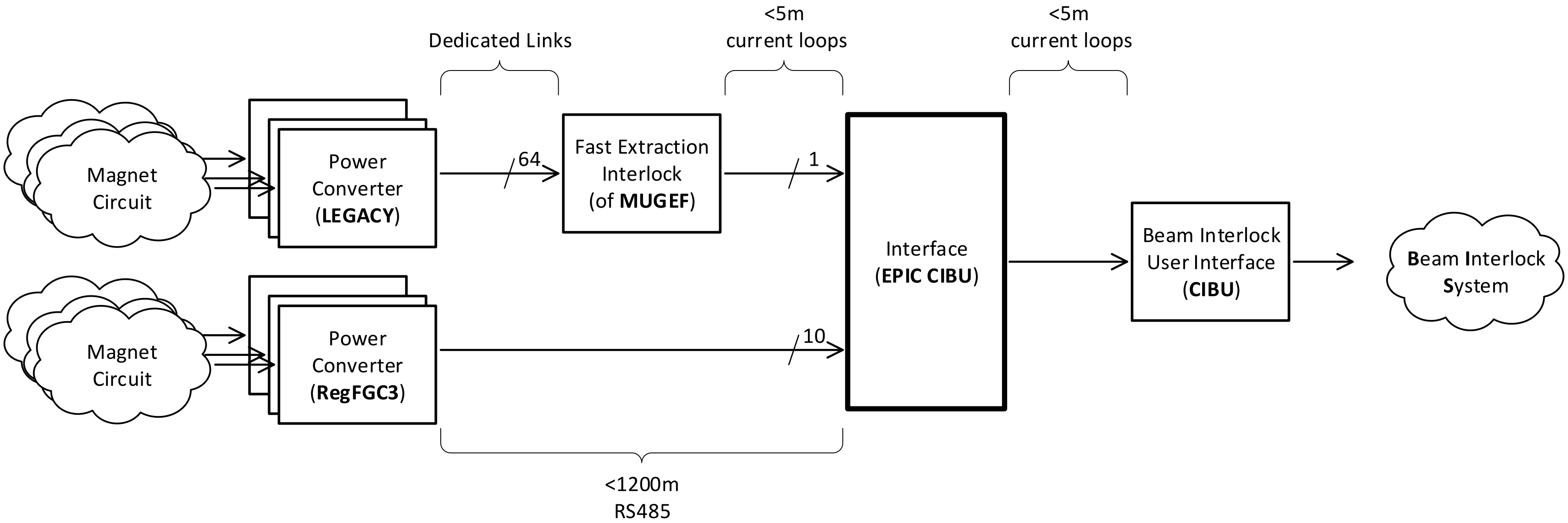
Need **BIS 2.0** but that's only planned for **~2025**

Solution: EPC User Interface to the Beam Interlock System
EPIC CIBU EDMS 2048658

Developed in **TE/EPC/CCE**, in **collaboration** with **TE/MPE/MI**

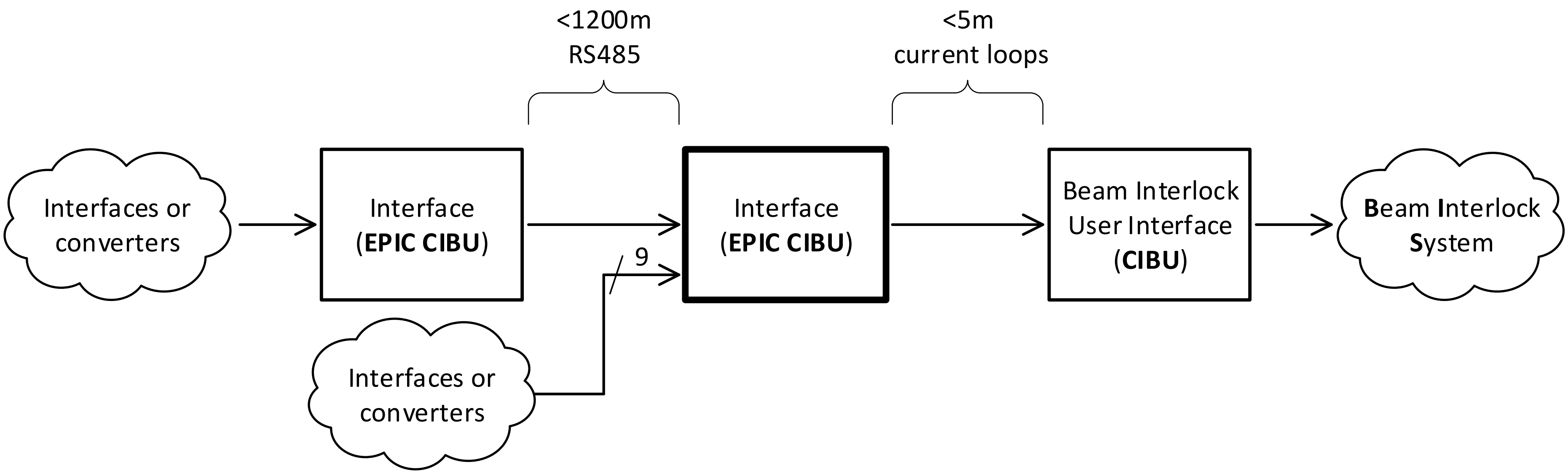
Combines:

Ten converter FLG_PERMIT signals from RegFGC3
One Fast Extraction Interlock FLG_PERMIT from legacy MUGEF



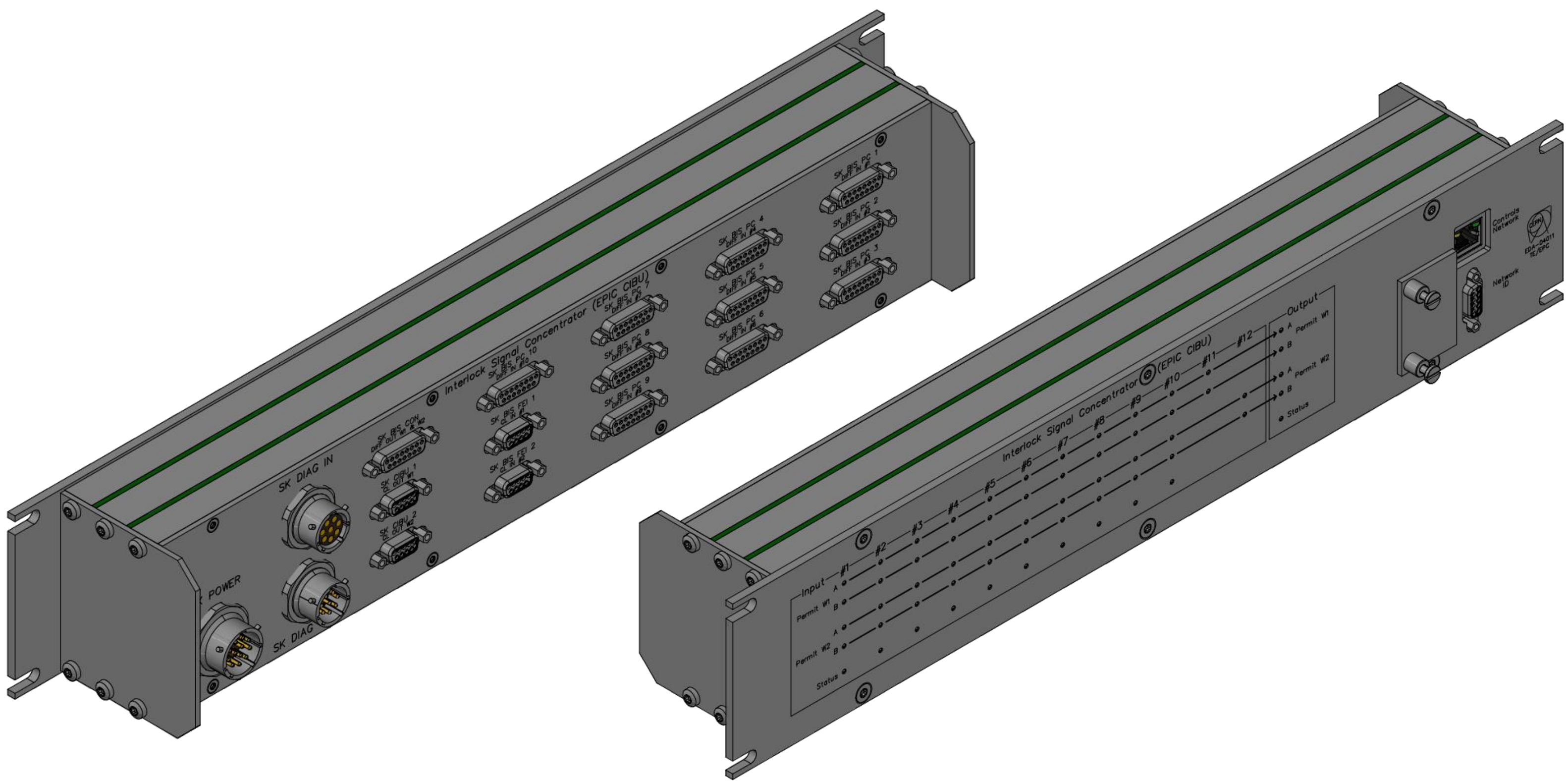
Each EPIC CIBU can handle two parallel redundant permit flags

EPIC CIBUs can be chained to extend the number of inputs



The example above could have **100 converters** connected to a single CIBU

A 2U version was built as a prototype, using low cost connectors:



A 3U version is in development, as a proof of concept,
using circular connectors

Coming Soon

EPIC CIBU uses the converter controls diagnostic platform (**QSPI DIM**), with read back at **50Hz**:

PERMIT INPUTS
PERMIT OUTPUTS
DISABLED CHANNEL STATES
VERSION of PCB / PLD

An on-board Ethernet socket is provided for "**Internet of Things**" diagnostics, such as

Transient Analysis
Remote Inventory management

This is **NOT** planned to be implemented

Software drives the Flags

- Similar integrity as before
- Hardware collates signals, maintaining critical / non-critical and A/B separation

FGC3 replaces some MUGEF channels:

- Corresponding software must migrate
- Interlock thresholds will now be in FGC3 not MUGEF

EPIC CIBU is in addition to FEI:

- Fast Extraction Interlock remains for some converters
- EPIC CIBU in addition – supervision should be aware of this

What changes for Machine Protection

EPIC and VS Beam Interlock electrically different to FEI

- Maintenance events might take longer to solve (at the start)
  - Before operation, the CIBU cabling needs electrical re-qualification started 12.04.2019

LINAC 4 is our test bed

- We don't know what we don't know: LINAC 4 is a milestone
  - D. Nisbet EPC / MPE link man
  - Identify further dependencies as we go

CERN

R2E-LHC600A & R2E-LHC4-6-8kA: Short-circuit tests

All converters and FGClites are tested in A7 prior to deployment.
FGClites, power converters & water-cooled DC cabling will be installed in P.1 & P.5.
These changes will validate the **R2E** power converter performance, full cabling and ventilation.

No short circuit tests are foreseen in P.7 where new FGClites & power converters are installed.

Hardware Commissioning (HWC) tests

FGClites will be installed in RRs and tested during HWC on LHC120A.
1-2 weeks of test time requested during Hardware commissioning for EPC Expert Regulation tests: variety of systems/magnets is big (load parameters, QPS, converter type).

QPS will experience less of the problems due to 0V-crossing (30% of population changed).

Load & Converter tests are done in the A7 test zone on each power module
but expert performance tests will need to be done post-deployment.

Qualified R2E projects

EPC Item / type	Status	TID [Gy]	SEE XS [cm²]	DD [/cm2]	Available	Deployed
FGClite 	In operation	200 *qualified*	$<10^{-13}$ *qualified*	$>10^{12}$ *qualified*	2016	**ARC:** EYETS **RR1/5/7:** LS2
RadDIM 	In operation	200 *qualified*	$<10^{-13}$ *qualified*	$>10^{12}$ *qualified*	2016	**ARC:** EYETS **RR1/5/7:** LS2
R2E-LHC 600A-10V 	Production	300 *qualified*	$<10^{-12}$ *qualified*	$>10^{12}$ *qualified*	2019	**RR1/5/7:** LS2
R2E-LHC 4-6-8kA-08V 	Production	60 *qualified*	$<10^{-12}$ *qualified*	$>10^{12}$ *qualified*	2020	**RR1/5/7:** LS2